Volume 39. Number 4. DECEMBER, 1925. $4.00 a Year. $1.25 a Number.

JOURNAL

OF THE

New England Water Works Association.

ISSUED QUARTERLY.

PUBLISHED BY
THE NEW ENGLAND WATER WORKS ASSOCIATION,
714 Tremont Temple, Boston, Mass.

Entered as second-class matter September 23, 1903, at the Post Office at Boston, Mass., under Act of Congress of March 3, 1879.

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1925—1926.

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A Member shall be an officer or employee of a public or private water works, an engineer, chemist or other person qualified to aid or interested in the advancement of knowledge relative to water works.

An Honorary Member shall be a person of acknowledged eminence in some branch of water supply or of engineering.

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The initiation fees and annual dues are as follows:

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This Association has six regular meetings each year, all of which, except the annual convention in September, are held at Boston.

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New England Water Works Association

ORGANIZED 1882.

Vol. XXXIX. December, 1925. No. 4.

This Association, as a body, is not responsible for the statements or opinions of any of its members.

THE WHEELING (WEST VIRGINIA) FILTRATION PLANT AND SOME OPERATING RESULTS.

BY JOHN F. LABOON.*

[*Read September 10, 1925.*]

Over 90 years ago, or, to be exact, in 1833, the city of Wheeling began the construction of a municipal water works, and in those 90 years it has been found not only practical, but necessary for expansion of the city and, consequently, the plant, to move the water works upstream twice.

The first move took place in 1892, 33 years ago, when the original pumping station was abandoned and a new station erected at Slacktown, about 1½ miles upstream. Additions to the building and machinery at Slacktown were made in 1898 and 1913. The supply was taken from the Ohio River and pumped to an open masonry reservoir having a capacity of approximately 3.5 million gal. and located 282 ft. above the river, where some of the river mud had an opportunity to settle out before the water was served to the users. Up to February of the present year, when the purification works began operating, raw Ohio River water had been served to the citizens of Wheeling, while the city fathers and the people they represented continued a controversy over the type of purification to be adopted. The history of Wheeling's struggle for pure water will be interesting to those who have ever experienced the vacillations of the public and politicians particularly in any civic movement involving water supply and water purification. As far back as 1908, citizens' committees, pure water commissions, engineer commissions, and other committees and commissions had been striving to solve the problem as to the type of purification best suited for Wheeling, without avail, until 1922 when rapid sand filtration finally won out. Wheeling's struggle for pure water was waged over a period of more than 15 years, during which time well systems on the Ohio River, the Smith system installed in the river bottom, — such as now in use at Parkersburg, West Va., — and rapid sand filtration have risen and fallen with the tides of human prejudices.

In the meantime, typhoid fever had been permitted to take its toll of lives and, without doubt, the reputation of the city has suffered from the

*Of The J. N. Chester Engineers, Pittsburgh, Pa.

lack of that prime requisite of human life, — pure water. Many reports were made during this period as to the types of purification works and the sources of supply. Of these reports, one under date of September 13, 1913, recommended a system of wells to be driven in the bottom of the Ohio River; another, dated March 23, 1914, recommended rapid sand filtration; while a third, dated June 21, 1915, recommended driven wells. Finally, on February 4, 1919, came the report, prepared by The J. N. Chester Engineers, designers of the filtration plant and the rest of the improvements, recommending rapid sand filtration, after an exhaustive study of both wells and filters and a consideration of a gravity storage supply.

It is interesting to note that during the period of expert and inexpert reporting, the citizens of Wheeling in 1914 by popular vote adopted the Smith (Parkersburg) crib system, but later in the same year, and again by popular vote, defeated the bond issue to provide funds to construct the very system they had previously chosen. Late in 1919, a bond issue, based on the report of February 4, 1919, which recommended a rapid sand filtration plant and new pumping station, also failed, notwithstanding the fact that the city administration and a citizens' pure water commission had approved the rapid sand filtration plant and new pumping station recommended by the consulting engineers.

Method of Bond Campaign.

The lesson taught by the failure of the 1919 bond vote was put to good use, however, when the bond issue of April, 1922, was presented to the voters of Wheeling. This bond issue was based on a supplementary report made by the writer's firm to the City Council, containing revised estimates of cost based on the then current prices which were somewhat different from those of late 1918 as embodied in the February, 1919, report. The supplemental report included also recommendations regarding the water supply of Warwood, Loveland, and Elm Grove, suburbs which had become part of Greater Wheeling since the report of 1919. Estimates of cost were made on the necessary improvements for supplying these new suburbs with filtered water from the purification plant which would also supply Wheeling.

The first move towards the realization of pure water came with the adoption, early in 1922, of the rapid sand filtration method of purification by the Pure Water Commission, consisting of City Council and five representative citizens. The next step was the placing of the facts before the public in such a manner as to convince them that the proposed improvements were necessary, — that rapid sand filtration was the type best suited to Wheeling's conditions and needs, — and that the cost involved was reasonable.

To this end, the writer was delegated by the city to organize a publicity bureau to act as a source of information for the newspapers, speakers, and the public. This period of service extended through six weeks just

previous to voting day. During this time, daily articles appeared in all of the newspapers giving data on the allied subjects of cost, taxation, and the economics of the problem at hand. Full details as to the improvements to be made and their costs and benefits were outlined through the various agencies at hand.

Every civic organization in the city; every club, particularly the Rotary, Kiwanis, and Lions Clubs: the Chamber of Commerce, and others, — were organized to work in systematic fashion for the bond issue. Street meetings, meetings in churches, schools, public halls, theatres, and in the homes were held, where facts concerning the water-works improvements were expounded and discussed. So-called "Four Minute Men" of Liberty Bond fame, gave talks on pure water at every evening movie performance in the city during the last week of the campaign. Slides giving typhoid statistics, and others illustrating various phases of the water question, were thrown on the movie screens between performances.

Displays of corroded pipe, hot-water heaters, photos showing the mud being removed from the reservoir, data concerning the various inefficient operations of the existing works, and the character of the raw water as compared with filtered water, were placed on exhibition in the two most prominent business windows on the main street, and these attracted more attention than any other single effort at publicity. Pamphlets containing facts covering the proposed improvements, their cost and benefits to be derived; comparative tax data, water rates, fire insurance, plumbing expense due to muddy or hard water, extra soap cost, labor-saving by use of soft water, etc., were distributed to every home in Wheeling, while large lapel buttons reading, "Vote for Pure Water," were passed out to the school children and in gatherings of all descriptions. Streamers were carried by automobiles to every part of the city, demanding pure water. Other agencies, such as newspapers which printed articles and stories by the State Department of Health, played an important part in the program of popularizing pure water; but one of the most important parts in the whole campaign was that played by the Chamber of Commerce and the Women Voters' League, jointly, who systematically got the voters out and to the polls on voting day. Automobiles and other vehicles were necessary for this purpose, but all were made available through these two organizations. Special attention was given to presenting convincing facts to some 10 000 people who were already supplied with either filtered water or well water by private concerns and who were, therefore, naturally not only apathetic, but rather hostile to the impending tax increase due to the water-works bonds. For the particular benefit of these people, who were being served rather hard water, demonstrations were given in audiences using standard soap solutions with waters of varying degrees of hardness to show the excessive amount of soap necessary with hard water. The result of all this effort was a turnout of one of the largest votes ever polled in the city of Wheeling on any measure, and the adoption for the first time in the history

of Wheeling of a pure water bond vote, which was decided by the overwhelming majority of 3 to 1.

The Water Works Improvements.

The Water Works of Wheeling by virtue of the bond issue has been improved to the extent of a filtration plant, pumping station, intake works, 20 600 ft. of 31-in. steel force and rising mains, 19 400 ft. of 16-in. cast-iron main, 5 600 ft. of 12-in. main, 6 000 ft. of 10-in. main, 10 000 ft. of 8-in. and 6-in. mains, 2 major 30-in. cross-connections, a 20-in. cross-connection, 5 million gal. reservoir capacity, and the purchase and assimilation of four private water plants which added 3 000 service connections to the existing system.

Water Consumption.

Wheeling until recently has been noted for its high rate of water consumption. For some years the rate has been 400 gal. per capita which is exceeded by few cities. In justice, however, it must be noted that Wheeling has some large steel industries and the like which consume abnormal quantities of water, thus giving rise to extraordinarily high per capita consumption rates. Daily peaks of 20 million gal. and monthly peaks of 19 million gal. have not been uncommon. This situation existed in 1922 when plans for the new water-works improvements were started and, furthermore, before the service lines of the private water plants had been added to the city's water-works system. Consequently, it was necessary to provide a purification and pumping plant of at least 20 million gal. daily capacity to take care of the immediate needs of the city and to project a system of metering of the industrial consumption before the new improvements were put into operation, if the capacity of the plant was not to be exceeded. Metering of industrials was begun in March, 1924, and completed shortly thereafter. Metering of the domestic and commercial consumers throughout the entire city was begun early this year after the filtration plant had begun to function. This metering has progressed at the average rate of 300 per month. That the consumption has been materially affected by metering of the industrials alone is apparent from a study of the records showing the monthly consumption and the number of services since 1915 (Fig. 1). Whereas the average consumption for 1923 before metering was 17.3 million gal. daily, the average consumption for 1924, which included three months of unmetered service, was 15 million gal. daily. For the past three months, since accurate records have been kept of the operation of the new filtration plant, the consumption has averaged but 12.6 million gal. daily even with 3 000 new service connections of the private water plants added to the system. At no corresponding period during the past ten years had the average consumption fallen below 15 million gal. From the data at hand, our prediction for an average yearly consumption of 12 million gal. under fully metered conditions will be more than realized.

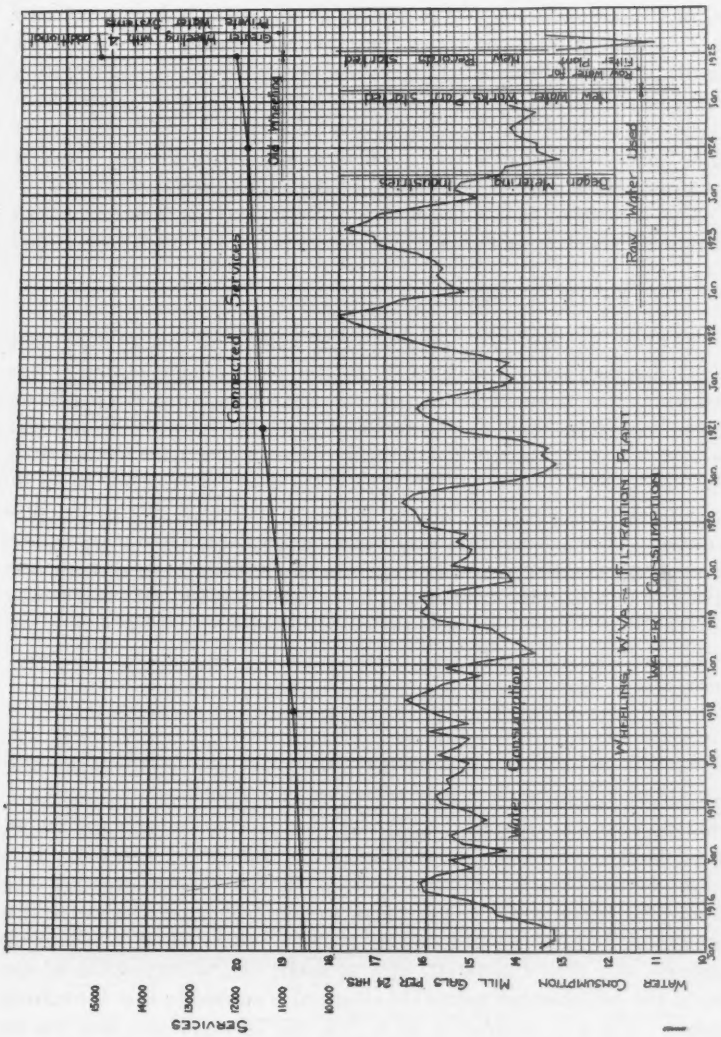


FIG. 1. — WATER CONSUMPTION.

Source and Quality of Supply.

The source of supply is the Ohio River just below the upstream city limits of Greater Wheeling. The stream at this point is highly polluted from the sewage of many cities and from the trade wastes of the enormous industries located upstream. In fact, the recent study of the pollution and natural purification of the Ohio River by the U. S. Public Health Service indicated a point on the river above Wheeling as being the most polluted part of the entire stream. Bacterial content of the raw water at the water-works intake of the city of Wheeling is indicated on Fig. 2. *B. Coli* are prevalent in 0.1 c.c. of river water, although there have been periods of as long as a month when only occasional *B. Coli* have been found in 1 c.c.

The Filtration Plant.

The filtration plant has a capacity of 20 million gal. per 24 hours and has been designed and constructed so that the plant can be ultimately enlarged to a capacity of 40 million gal. It is so designed in regard to its chemical equipment and mixing facilities that the filtration works can serve as a softening plant. The filtration plant is located, together with the pumping station and intake works, on the banks of the Ohio River at a point 9 000 ft. upstream from the pumping station at Slacktown, just abandoned. The new location is part of a combined park and playgrounds which the city has developed since the original purchase of land was made for the new improvements, making a desirable setting for the water-works improvements. The purification works consist of a grit chamber, mixing chamber, settling basins, filters, coagulant house, wash tank, and clear-water storage.

Grit Chamber.

The raw water is taken from the river by means of an intake pier, conveyed through a 36-in. suction line to the low service pumps, and then discharged into the grit chamber through seven 16-in. riser pipes whose tops are located 2 ft. $2\frac{1}{2}$ in. above the normal flow line. The water falls upon steel splash plates located at each of the risers and thence into the grit chamber. The water flows to a perforated collecting wall at the opposite end of the basin, passing through it into a flume leading to the mixing chamber. Any heavy material, such as sand, etc., is settled out of the water in the grit chamber before the chemical is applied to it in the mixing chamber. The grit chamber is 98 ft. 6 in. by 56 ft. in plan and has an effective depth of 20 ft. 6 in. The grit chamber has a capacity of 850 000 gal. or slightly more than one hour's detention period when the flow through the basin is at the capacity rate of 20 million gal. daily. The walls are designed for cantilever action to resist full water pressure on one side and full earth pressure on the opposite side. The walls are brick veneered around the entire outside wherever they appear above the berme, except

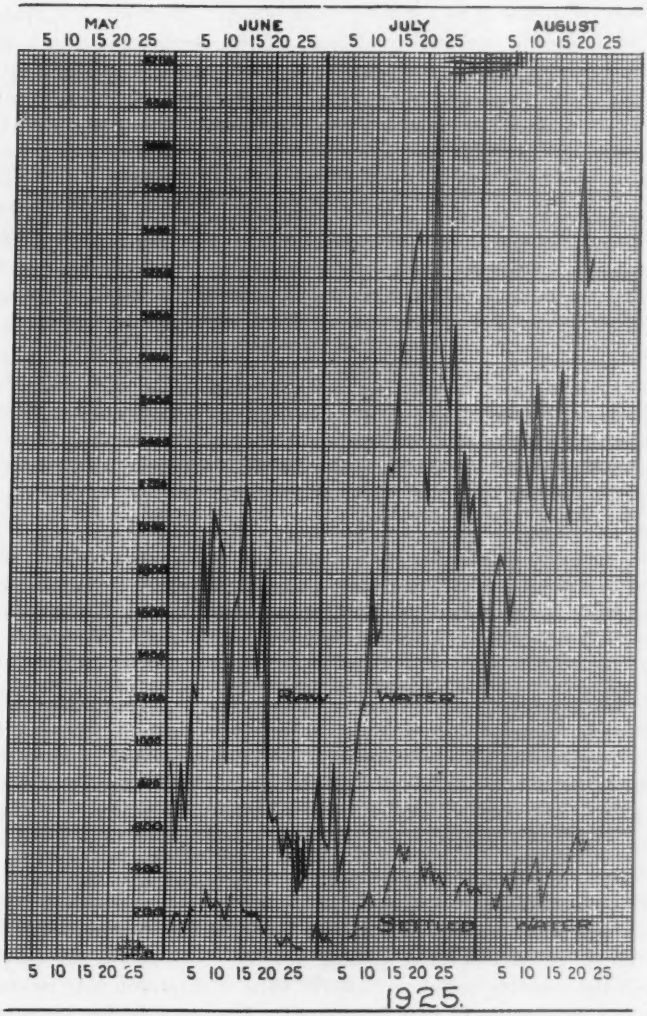


FIG. 2. — BACTERIAL CONTENT OF RAW AND SETTLED WATER.

that the base and coping are concrete. The bottom consists of a double concrete floor having a total thickness of 9 in. and is built without any reinforcing steel. The vertical joints are offset and waterproofed between the two layers by means of an asphalted membrane. There are provided two 12-in. hydraulically operated mud drain valves discharging into a 12-in. cast-iron sewer under the floor, this sewer being enlarged to 16 in. at the connection with the second mud valve. The floor is sloped 5 per cent. in the longest direction for draining purposes, while the sewer is sloped 1 per cent. Three $2\frac{1}{2}$-in. hose connections taking water from a 4-in. pressure line are provided on the north wall for cleaning purposes. A hydraulic operating panel for the mud valves is located in the mixing-chamber building. The grit chamber is of open construction for, although ice forms in appreciable thickness in the climate of Wheeling, our experience has been that open basins are entirely feasible in such climate. Should it become desirable to apply any chemical to the raw water before it enters the grit chamber, provision has been made in the Venturi meter manhole adjacent to the mixing chamber where a rubber hose chemical pipe is connected into the Venturi meter throat for this purpose. The Venturi meter is located in the raw water discharge line leading to the grit chamber. The take-off flume at the end of the grit chamber is so arranged by means of piping that raw water can be supplied to it directly from the pumps, thus by-passing the grit chamber, and further arranged so that the effluent from the grit chamber can be by-passed around the mixing chamber to the settling basins. This arrangement also permits of the raw water by-passing both the grit chamber and mixing chamber and passing directly into the settling basins if desired.

Mixing Chamber.

The mixing chamber is 56 ft. by 55 ft. 6 in. in plan and has an average effective depth of 19 ft. 9 in., making a net capacity, after deducting the baffles, of 415 000 gal. or 30 minutes' detention when operated at the rate of 20 million gal. daily. A brick building of suitable design and provided with heat extends over the entire mixing chamber to permit of comfortable winter operation. Five concrete baffle walls divide the basin north and south into six channels which are in turn divided into vertical water passages by means of 2-in. T. & G. white pine wood baffles which are capable of adjustment to any desired mixing velocity. By-passes are provided through the concrete baffles so that the time of detention may be reduced to 10 and 20 minutes as may be desired. The wood baffles are provided with adjustable gates hung from the bottom of the underflow baffles and attached to chains hung from the top, permitting of adjustment so that surge velocity may be obtained if found necessary for more efficient operation. Two 8-in. hydraulically operated mud drain valves have been provided with operating mechanism located at the building entrance level. Loose sectional wood walk ways have been strung over the tops of the walls

for operating convenience. The concrete walls are designed for conditions similar to those described for the grit chamber. Rubber chemical hoses are brought into the mixing chamber by means of a 16-in. cast-iron pipe underground conduit leading to the coagulant house. The hose is strung on channels supported from roof trusses, so as to afford hose adjustment for the application of chemicals at any desired point in the baffling system.

Settling Basins.

There are two settling basins adjoining the grit chamber and mixing chamber with a common dividing wall between, each basin being 82 ft. by 150 ft. in plan, and 18 ft. in effective depth. The combined capacity of the two settling basins is $3\frac{1}{3}$ million gal., which is equivalent to a detention period of 4 hours when the basins are operated at the capacity of 20 million gal. daily. The walls are of concrete and of cantilever design similar to those of the grit chamber and mixing chamber. A single baffle wall extends longitudinally through the center of each basin so that the mixed water, as applied from the mixing chamber, passes out of the dispersion wall in one direction, swings around the concrete baffle and returns in the opposite direction to the collecting weir. Six $2\frac{1}{2}$-in. hose connections are provided at the concrete baffle wall of each basin for flushing purposes. There are six 12-in. hydraulically operated mud drain valves in each basin. The floors are sloped 5 per cent. in the longest direction to the drain valves. The floors are of similar construction to that described for the grit chamber. Copper expansion joints are provided at approximately 50-ft. intervals in every supporting wall of the settling basins, mixing chamber, and grit chamber. The settling basins are open like the grit chamber. Hand-operated sluice gates are provided in the various flumes at the west end of the settling basins so that either basin may be cut out or either series or multiple operation obtained. An 18-in. overflow pipe is provided in each of the settling basins. The concrete walls are brick veneered on the exterior above the berme line like the walls of the mixing chamber and grit chamber. All water piping where it is not cast iron is genuine wrought iron. A concrete walk way with railing is provided on the west end of the basins. Chemical piping is arranged so that double coagulation is possible, such as is practiced with effective results at Portsmouth, Ohio.

Filters.

There are ten filters arranged in two rows and divided by a common pipe gallery and operating floor. The filters are of concrete throughout, each filter having a rated capacity of 2 million gal. daily. Each filter is divided into two sand beds by a concrete cross-drain gutter, the sand beds being 28 ft. 6 in. by 12 ft. 6 in. each, in plan thus making a total sand area of 712.5 sq. ft. per filter unit. The sand is 30 in. thick, overlying an 18-in. thickness of gravel which is graded from $2\frac{1}{2}$ in. at the bottom to $\frac{1}{8}$ in.

at the top. The sand has an effective size of .35 to .40 mm. and a uniformity coefficient of 1.40. The gravel is supported by an 8-in. concrete false bottom floor in which are set $\frac{3}{8}$-in. bronze pipes connecting the false bottom with the filter. Brass strainers of the umbrella type are screwed into the strainer pipes. The strainers and pipes are located on 6-in. centers both ways throughout the filters. The false bottom is of concrete throughout, designed to resist a water pressure of 20 lb. per sq. in. To resist this pressure, which is equivalent to 2 880 lb. per sq. ft. required the installation of built-up channel beams located on 3-ft. centers, in both top and bottom of the chamber, these channels furthermore being tied together by 4-in. by $\frac{1}{2}$-in. plates riveted to the channels. Both channels and the bars are encased in concrete. The concrete floors, both top and bottom, are designed as slabs spanning between the channel beams and are reinforced with steel. Our first extensive use of the false bottom was in our design of the Erie, Pa., filter plant, and this type of bottom has since been a feature of practically all of our filter-plant designs. Its claim to our preference is that the false bottom acts as a pressure chamber for the uniform distribution of wash water throughout the filters, and also as a ready means of detecting sand leaks through the strainer system and for its removal and replacement. Access to the false bottom is had through a flanged manhole provided in each of the filters in the pipe gallery. Steel wash troughs painted in aluminum are provided on 7-ft. $1\frac{1}{2}$-in. centers for the collection of wash water. These troughs terminate in the concrete cross gutters. The cross gutters lead to 24-in. branch sewers, which terminate in a 24-in. main, located under the floor, one for each row of filters.

A 48-in. cast-iron coagulated water line extends the entire length of the pipe gallery and connects to the settling basins. A 16-in. connection is taken off for each filter. The wash-water main is a 24-in. cast-iron pipe with an 18-in. branch leading to each filter. The effluent pipe from each filter is 14 in. in diameter and terminates in the clear well in an upturned ell which acts as a water seal. A rate controller is provided for each filter. Each filter is, furthermore, equipped with an 8-in. rewash connection to the sewer. A hydraulic operating table is located on the operating floor in front of each filter. There are mounted on each table the control valves, an indicating loss-of-head gage, and an indicating rate-of-flow gage. A master control table containing the mechanism for setting all of the filters simultaneously at any desired rate without having to go to the individual filter operating tables, is located in the lobby of the coagulant house. In addition to the control mechanism, there are mounted on the master control table a master indicating rate-of-flow gage, an indicating, registering and recording raw water Venturi gage, an indicating clear-well gage, a recording wash tank level gage, an indicating, registering and recording wash-water gage, sample pumps for raw water, coagulated water, and treated water, and a central fountain and fish bowl.

A stairway leading from the operating floor to the pipe gallery, and

located at one end of the pipe gallery opposite to the end which opens into the coagulant house basement, provides a second entry to the pipe gallery and serves besides as a ventilator so as to render the pipe gallery more dampproof than is ordinarily the case.

The operating floor is overlaid with red and buff tile alternated in 12-in. squares. The tops of the filter walls on the interior of the building are capped with 2-in. cut limestone. A concrete clear well, 150 ft. by 28 ft. 3 in. in plan, and with an effective depth of 8 ft., extends under each row of filters. These clear wells are connected to a pump suction well located in the head house by means of 42-in. cast-iron pipes controlled by hydraulic valves. The high-service pumps take their suction from the pump suction well. The pump suction well is 26 ft. 10½ in. by 24 ft. 3 in. in plan and has an effective depth of 12 ft. The combined capacity of the clear wells and pump suction well is 570 000 gal., which makes a storage of slightly more than 40 minutes when the plant is operating at the rate of 20 million gal. daily. The clear well is equipped with high and low water alarms which ring in both the pumping station and filter buildings.

The superstructure is of brick with steel sash windows, while the roof is tar and gravel laid over T. & G. yellow pine sheathing.

Wash water is stored in a steel tank located adjacent to the filter plant and having a capacity of 125 000 gal., which is sufficient to wash two filters before refilling. The tank is provided with automatic control apparatus actuating two 1 000 gal. per minute pumps located in the basement of the coagulant house which take their suction from the pump suction clear well and pump into the wash water line. A rate controller is located in the main wash-water line in the basement of the coagulant house in order to provide a uniform rate of flow during the washing period.

Coagulant House.

The coagulant house, or head house, is a single-story structure over the laboratories and lobby and a four-story building on the west end. This building is located at the south end of the filters, the two buildings being in common. In the coagulant building are housed the master control equipment, gages, etc., the laboratories, the superintendent's office, a clerk's room, a record storage room, a toilet room, a shower and locker room, and a chlorine room on the first floor; the dry chemical feed machines on the second floor; the daily feed hoppers on the third floor; and the chemical conveying and elevator equipment, a dust arrester, and the concrete storage bins for the chemicals on the top floor. In the basement are located the pump suction clear well, wash pumps, wash-water rate controller, Venturi equipment, two heating boilers, a coal storage bin, and the chemical pulverizer.

Three fully equipped laboratories have been provided for complete chemical and bacteriological analyses. The floors in the laboratories are of hexagonal vitrified tile, while the walls up to 4 ft. 6 in. from the floor are of

6-in. x 3-in. vitreous white tile. The walls and ceilings of the offices and hallways are plastered with a sand finish. The lobby floor is finished in Tennessee marble, while the walls at the bottom are finished to a height of 3 ft. in white Italian marble. A moulded plaster cove for effecting indirect lighting runs around the entire lobby near the ceiling line.

Two vacuum type chlorinators, manually controlled, are located in the chlorine room. A direct reading Toledo platform scale is installed for checking amounts of chlorine used. The coagulant house is designed to handle chemicals in bulk form direct from the railroad cars. A power shovel is used to unload the cars and to convey the material to a hopper on the outside of the building. The hopper leads to a hammer crusher and pulverizer below. After the material has passed through this pulverizer, it is automatically conveyed by a vertical continuous canvas bucket conveyer and deposited into a horizontal screw conveyer which in turn conveys the material to chutes leading to the individual concrete storage bins. The entire conveying equipment is enclosed so as to be as nearly dust-proof as it is possible to obtain. An additional precaution has been provided in the installation of a dust-arrester which removes the dust from the conveyer shaft and in the vicinity of the workmen unloading chemicals. The dust-arrester also has connections at the daily feed hoppers on the third floor for the same purpose. The chemicals are stored in five concrete covered bins, each 11 ft. 6 in. by 13 ft. 3 in. in plan inside and of an average depth of 16 ft., thus giving a minimum total storage capacity of 60 tons per bin as based on lime. The bins are comparatively air-tight so that there will be little if any air-slaking of bulk lime when stored therein.

Each of the concrete bins is equipped with a buzz roller gate located at the end of the hopper bottom which discharges through a chute into the daily chemical hoppers. The latter are made of steel. The dry-feed machines connect directly to the bottom of the daily hoppers on the floor below. Of the five dry-feed machines, two are arranged for feeding either alum or iron, two for quicklime, and the fifth for quicklime, soda ash, alum, or iron. The dry-feed machines are manual-controlled and operated by means of water motors. Each machine has a daily capacity of 16 000 lb. of quicklime or 20 000 lb. of iron or alum, thus permitting a rate of feed ranging from 0.1 to 5.7 grains per gal. of lime and 0.5 to 7.1 grains per gal. of iron or alum when the plant is operating at the rate of 20 million gal. daily. A water ejector has been installed with each dry-feed machine to discharge the chemical solution into the mixing chamber or other points of application provided for, so that a great deal of the disagreeable pipe work under the floor and the clogging of lines experienced in gravity systems through chemical settlement have been eliminated.

One of the distinct features of the chemical treatment at the Wheeling filter plant is the use of dry-feed machines which feed, slake, and liquefy quicklime in one operation. The ordinary procedure in the past has been to use hydrated lime wherever dry-feed machines were desired and to use

weighing machines, slaking tanks, and solution tanks for quicklime. The quicklime feeder being used at Wheeling takes up much less space and costs less than the solution feed apparatus does, and eliminates a great deal of the undesirable slopping over which is ever present with the solution feed. The present apparatus has been functioning for more than six months, during which time it has been necessary to rebuild the machines in part to make them dependable. At the present time the machines are operating satisfactorily, but time alone will develop whether or not these machines will prove capable of rendering year after year, without too great maintenance, the difficult service they are designed for. Some of the difficulty with these machines has been in regulating the water supply for slaking purposes and the carrying off of the steam generated in the slaking processes, which becomes of some moment when feeding large quantities of quicklime; but these matters have been practically settled. The present apparatus justifies the statement that the feeding of the average calcium lime in dry form through a dry-feed machine is practical. A considerable saving has been made in the initial cost of the equipment as compared with the cost of a solution feed type. Further tests of the apparatus are contemplated in the immediate future when definite data as to operating results will be made available. Cold water is being used for slaking and has been found to be satisfactory so far. This water, however, is preheated in the water jacket surrounding the chamber where the slaking takes place so that a heated water is obtained in effect.

An electric freight elevator has been installed in the coagulant house tower reaching from the basement to the top floor.

The coagulant house superstructure is of brick throughout with limestone trim and copings. The roof over the one-story structure is tar and gravel, while over the tower it is sheet lead. The windows are steel sash. Casement windows have been provided for the laboratories and offices.

Two steam boilers, each having a capacity of 8 750 sq. ft. of heating surface, are installed in the basement of the coagulant house to provide heat for all the buildings, which include the mixing chamber, coagulant and filter house, and pumping station.

Personnel.

At the filtration plant, the operating force consists of:

1 chemist.
3 operators (1 each 8 hr. shift.)
2 laborers.
½ time janitor.
½ time machinist.
½ time machinist helper.

The two laborers unload chemicals, act as ground keepers, and perform any other menial tasks that may develop at either the filter plant or pumping station.

The pumping station operating force consists of:

3 operators.
1 extra operator.
½ time janitor.
½ time machinist.
½ time machinist helper.

A superintendent has been appointed this year to take charge of the entire water-works system of the city. (Wheeling had been without a superintendent for 10 years.)

Operating Results.

The filtration plant was put into full operation February 23d of the present year and has since continued to function without interruption. In the desire to supply filtered water at the earliest opportunity, the filters were started before record blanks could be designed and, therefore, no detail records are available until June 1st. Curves have been drawn to show the chemical and bacterial character of the water, both raw and filtered, from June 1st to August 22d. Figure 2 depicts the bacterial nature of the raw and settled water and the proportion removed in the coagulating and settling processes. The bacteria at 37° C. in the raw water give some indication of the pollution of the Ohio River at the Wheeling intake. The maximum percentage of bacteria removal accomplished in the processes of coagulation and settlement at any time was 90; the minimum 60; and the average 84 per cent. The number of 37° C. bacteria in the filtered water did not exceed 50 per c.c. at any time, while the bacteria in the chlorinated water reached on one occasion a maximum of 39 in 1 c.c. of one sample, but on no other occasion has the count been greater than 12 per c.c. At no time were *B. Coli* found in 10 c.c. of filtered water, although present in about one-half of the 10 c.c. settled water samples. Chlorine is added to the filtered water in the pump suction well at the point where the mains from the filter clear wells enter. The dose of chlorine ranged from 0.26 to 0.3 p.p.m.

In Fig. 3 are shown the hardness, alkalinity, and carbonic acid content of the raw and treated waters. The hardness rose during July, but fell towards the close of the month after a rainy period. The curve shows the hardness mounting again in August and the prospects are that it will reach new levels, due to the drought which is now upon the Ohio Valley. A demonstration of the purification plant as a softening plant has been put off until the hardness reaches somewhere near maximum figures, and it is probable that such a condition will soon be realized. A carload of soda ash has been in storage for some time awaiting the softening demonstration.

The alkalinity of the raw water has reached zero, but the water has not been acid so far. An effort has been made to maintain the alkalinity of the filtered water at 10 p.p.m., but this has not been realized entirely because of lack at times of the proper labor personnel; but this latter is being ad-

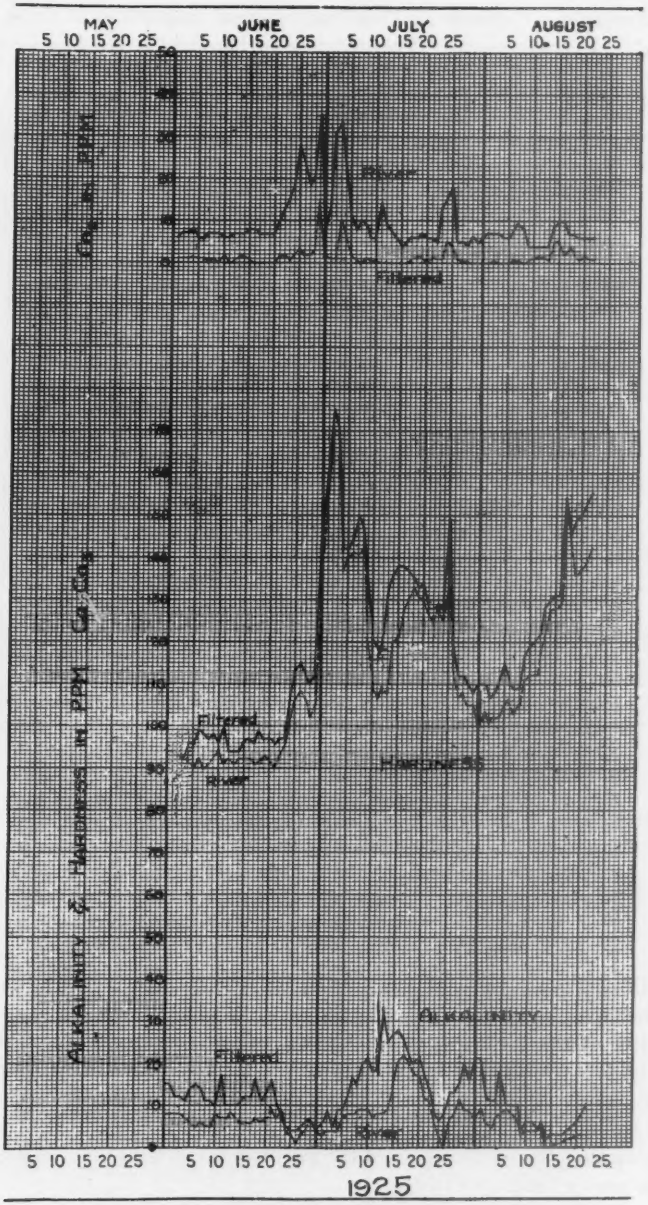


FIG. 3. — HARDNESS, ALKALINITY AND CARBONIC ACID CONTENT OF RAW AND TREATED WATER.

justed rapidly. Carbonic acid has reached great proportions at times, due, probably, to trade wastes. The carbonic acid content in the filtered water has been reduced to a minimum by treatment with lime.

Turbidities of the raw and settled water are illustrated in Fig. 4. The turbidity of the raw water is low during the summer months, rising at Wheeling to one single peak of 250 p.p.m. In spring and the fall, tur-

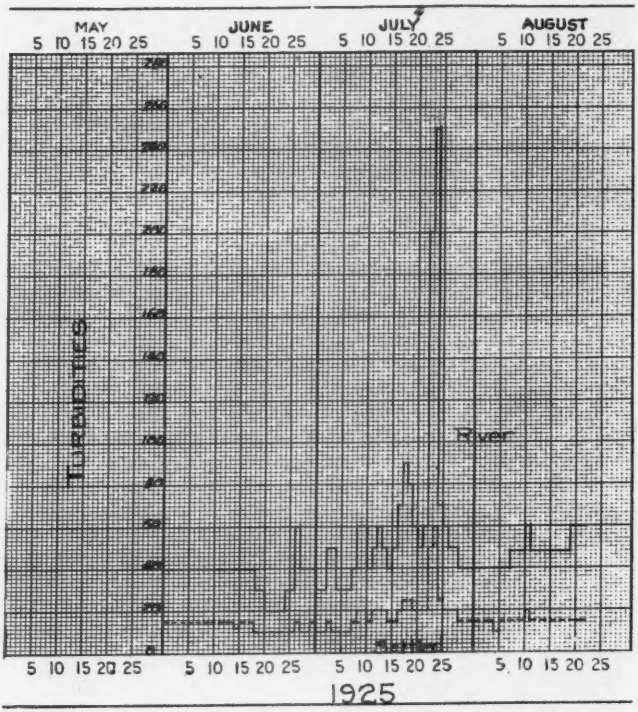


FIG. 4. — TURBIDITY OF RAW AND SETTLED WATER.

bidities in the raw water of over 1 000 p.p.m. can be expected. The quantity of chemicals and wash water, the temperature of the raw water, the length of filter runs and the iron content of the raw and filtered water are shown in Fig. 5. Wash water and filter runs will be improved upon as the operating forces become more expert in their duties. The chemical treatment will also be improved upon, it is hoped, by the same measure. It is of interest to note that the temperature of the raw water averaged practically 90° F. for a week's readings in June.

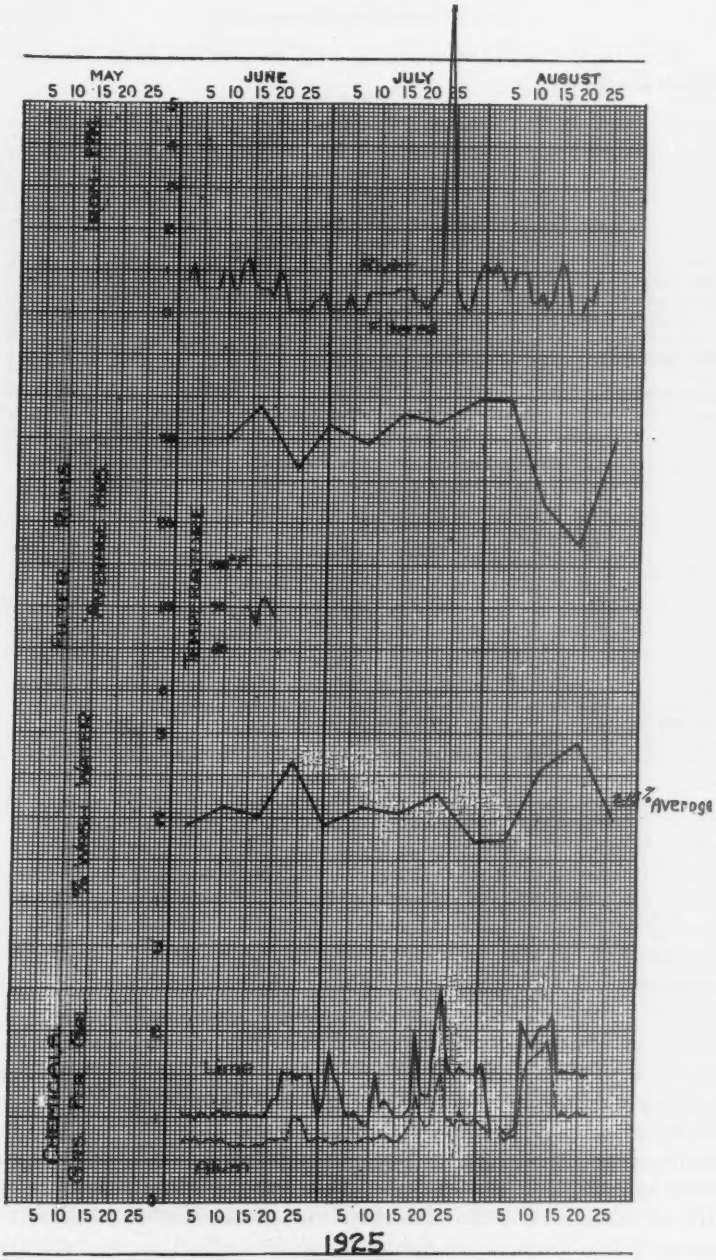


FIG. 5. — OPERATING RESULTS.

Operating Costs.

Some results as to the operating costs as compiled from the records, are as follows:

COST OF FILTERING.
June 1 to August 22.

	Total.	Per Mil. Gal. Filtered.	Per Mil. Gal. Pumped into Mains.
Labor	$2 770	$2.68	$2.73
Chemicals	3 196	3.09	3.15
Power and Light	95	.09	.09
Low Service Power Wash Water	82	.08	.08
Wash pump	74	.07	.07
Heat (proportion)	150	.15	.16
Gas	5	.01	.01
Ejector water, etc.	210	.21	.22
Totals	$6 582	$6.38	$6.51

COST OF PUMPING.
Electric Power High and Low Service.
June 1 to August 22.

	Total.	Per Mil. Gal. Pumped into Mains.
Labor	$2 676	$2.64
Power and Light	13 634	13.48
Oil and Waste	250	.25
Heat (proportion)	100	.10
Totals	$16 660	$16.47

Total cost of filtering per mil. gal.	$6.51
Total cost of pumping per mil. gal.	16.47
Total cost of water per mil. gal. delivered into the mains, not including fixed charges	$22.98

In any comparison of these data with similar data, it is to be noted that the new Wheeling pumping station is electrically operated.

Construction Costs.

The filtration plant, although of the most up-to-date type and of substantial and architecturally pleasing construction, was built at a comparatively low cost. This result was obtained in the face of the fact that prices had increased 25 per cent. (by price index) from the time bonds were voted, early in 1922, until the time plans were completed and bids could be received on April 11, 1923. The detail cost of the filtration plant, as taken from the final estimates of 8 contracts and semi-final of two contracts, is as follows:

COST OF FILTRATION PLANT.

	Contract Price.	Extras.	Total.	Chargeable to Filter Plant.	Cost Per Mil. Gal. Capacity.
Railroad Siding	$3 000	$100	$3 100	$2 000	$100
Excavation and Grading					
Coagulating House and Filter Building	11 000	420	11 420	11 420	571
Settling Basins	25 000	680	25 680	25 680	1 284
Concrete Work					
Coagulating House and Filter Building	106 092	2 390	108 482	108 482	5 425
Settling Basins	117 180	1 705	118 885	118 885	5 944
Miscellaneous Equipment in Coagulating House and Filter Building	14 908	275	15 183	15 183	759
Miscellaneous Equipment in Settling Basins	17 820	1 190	19 010	19 010	950
Outside Piping	25 000	330	25 330	25 330	1 266
Superstructures					
Coagulating House and Filter Building	102 915	3 030	105 945	105 945	5 298
Mixing Chamber	16 395	405	16 800	16 800	840
Electrical Work	8 500		8 500	5 000	250
Freight Elevator	5 780		5 780	5 780	289
Heating Plant	4 240		4 240	2 800	140
Filter Equipment	93 710	8 604	102 314	102 218	5 111
Wash Tank	9 500	2 424	11 924	11 924	596
Conveying Apparatus	9 470	28	9 498	9 498	475
Gate Valves	9 300		9 300	9 300	465
Plug Valves	2 072		2 072	2 072	103
Sluice Gates	4 613		4 613	4 613	231
Venturi Meter	3 000		3 000	3 000	150
Total	$589 495	$21 581	$611 076	$604 940	$30 247

Percentage of extras to contract prices — 3.66.

The increase in prices just previous to the letting of contracts made it necessary to economize somewhat in matters of lesser importance, but later, when it was found, upon receipt of bids, that there remained some moneys which could be used in betterments, the city officials agreed to restore some of the finer features which had been removed in the name of economy. Consequently, the extras in most cases cover such matters as wash pumps, a wash-water controller, superior hardware, superior lighting fixtures, additional stone work, better floor finishes, the finishing of two storerooms, additional plaster and painting, etc. In the case of the wash tank, the entire sum of extra was spent in testing the foundations, which were found to have been affected through some action underground which even yet has not been definitely explained except that a deep excavation, several hundred feet away, is suspected to have exerted an influence on some underground stratum which allowed the wash-tank foundations to settle. This occurred, however, before the tank was placed on the foundations and, therefore, involved only the testing to maximum load of each foundation

pier with pig iron. No appreciable settlement occurred during the test or since and no additional foundations were necessary. As a precaution, however, the tank tower was equipped with additional bracing to guard against any future movement.

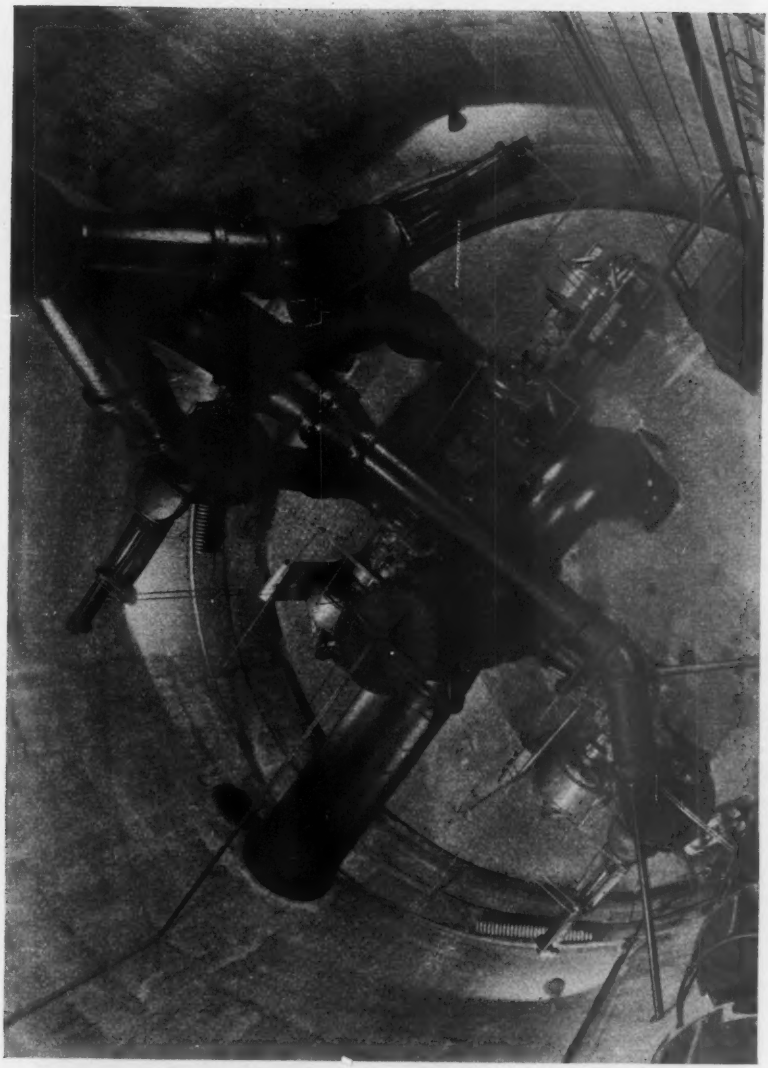
The cost of all of the improvements included in the bond issue up to date are as follows:

	Contract Price.	Extras.	Total.
Filtration Plant	$589 495	$21 581	$611 076
Pumping Station	266 925	14 699	281 624
Intake Pier	37 190	.....	37 190
Intake Pipe	27 600	47	27 647
Intake Tunnel	33 500	.....	33 500
Steel Force Mains	293 658	12 183	305 841
Distribution Reinforcement	266 195	12 708	278 903
Cross-connections	38 674	4 893	43 567
Reservoirs	138 370	5 742	144 112
Totals	$1 691 607	$71 853	$1 763 460

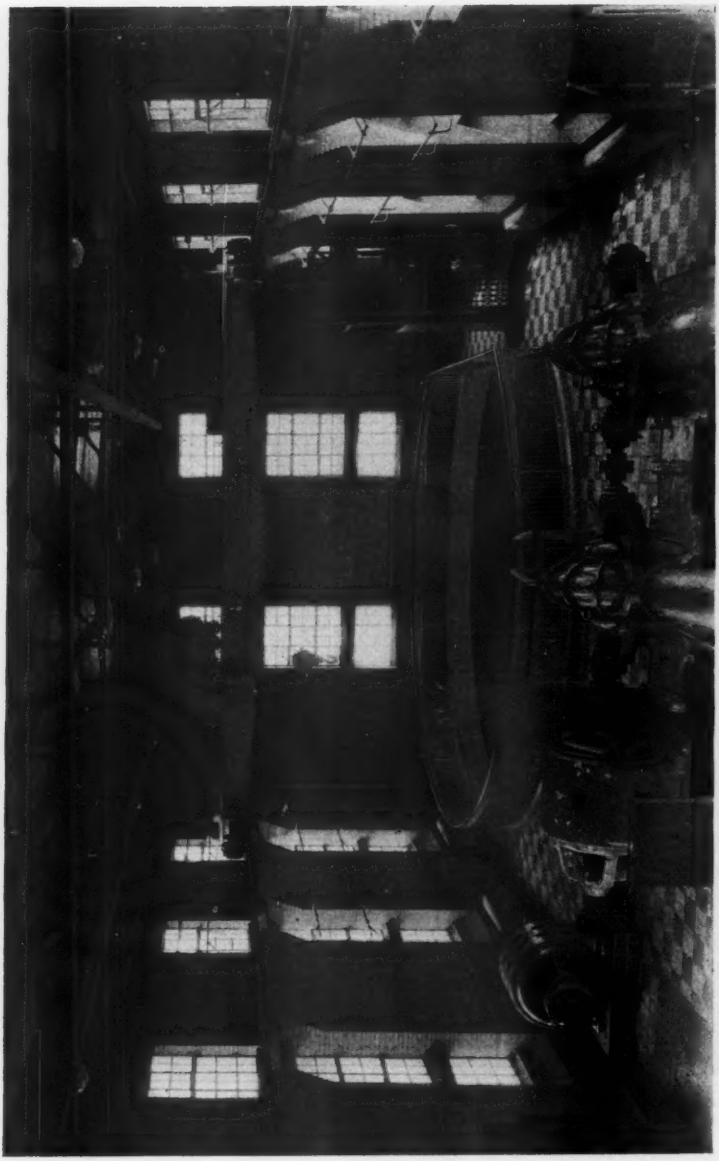
Percentage of extras to contract price 4.25
Purchase price of four private water plants $279 193

The extras in most cases were occasioned in the same manner as explained for the detail cost of the filtration plant. Under distribution reinforcement, the original plans did not contemplate any lining for a tunnel which passed through rock and in which was laid a 16-in. force main from the reservoirs to one of the private distribution systems purchased by the city. The city finally decided to line this tunnel with concrete at an extra cost of $6 670. In the pumping station, it was decided to put in a transformer bank for lighting and station power and to construct a special room to house it. The city furthermore ordered almost $7 000 worth of spare parts for the pumps and motors and added this expenditure as an extra to the pump contract, which is included in the cost given above for the pumping station. Under cross-connections, additional valves and manholes were installed. Considerable rock and an underground spring creating a fairly good sized slide served to make up most of the extra for the reservoirs.

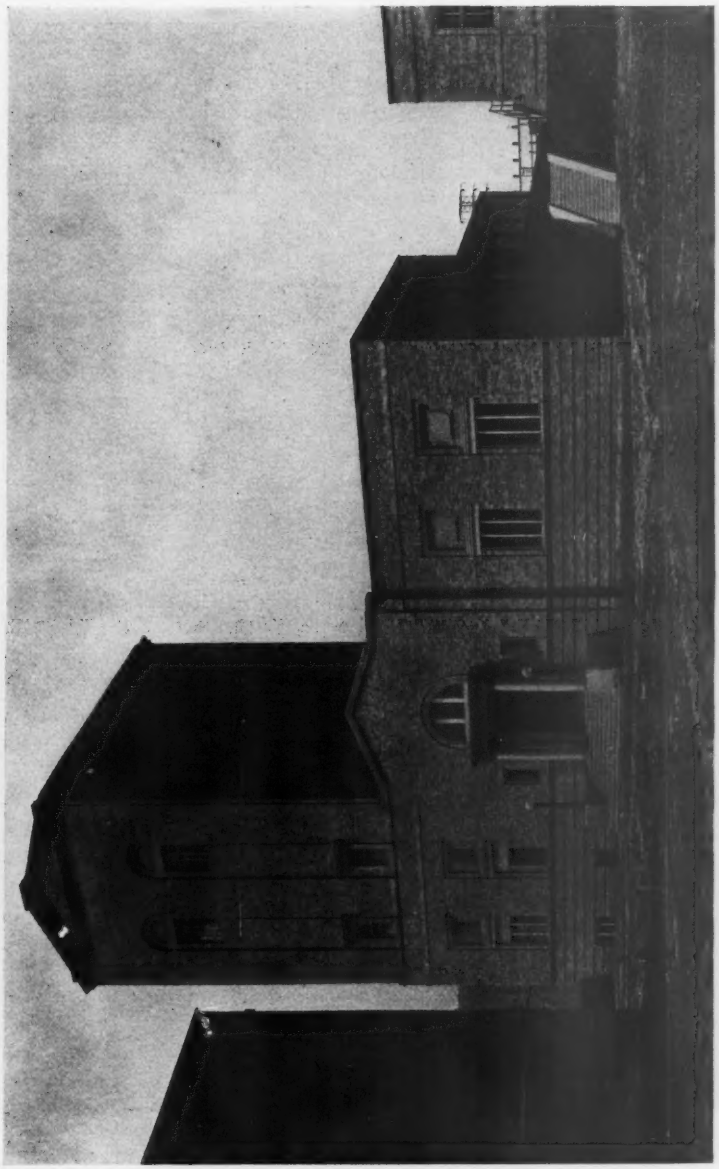
The bids were opened April 11, 1923, and filtered water was turned into the city mains permanently February 23, 1925, approximately 22 months after receipt of bids. C. H. Dowler was City Manager when work was started. He was succeeded shortly afterwards by J. S. Butts who served until July 1st of the present year. H. L. Kirk is the present City Manager, J. W. Shull is Superintendent of Water Works, and G. E. Rickard is chemist in charge of filtration. The writer directed the improvements from the Pittsburgh office of The J. N. Chester Engineers. F. S. Stow, with four assistants, directed the work in the field as resident engineer.



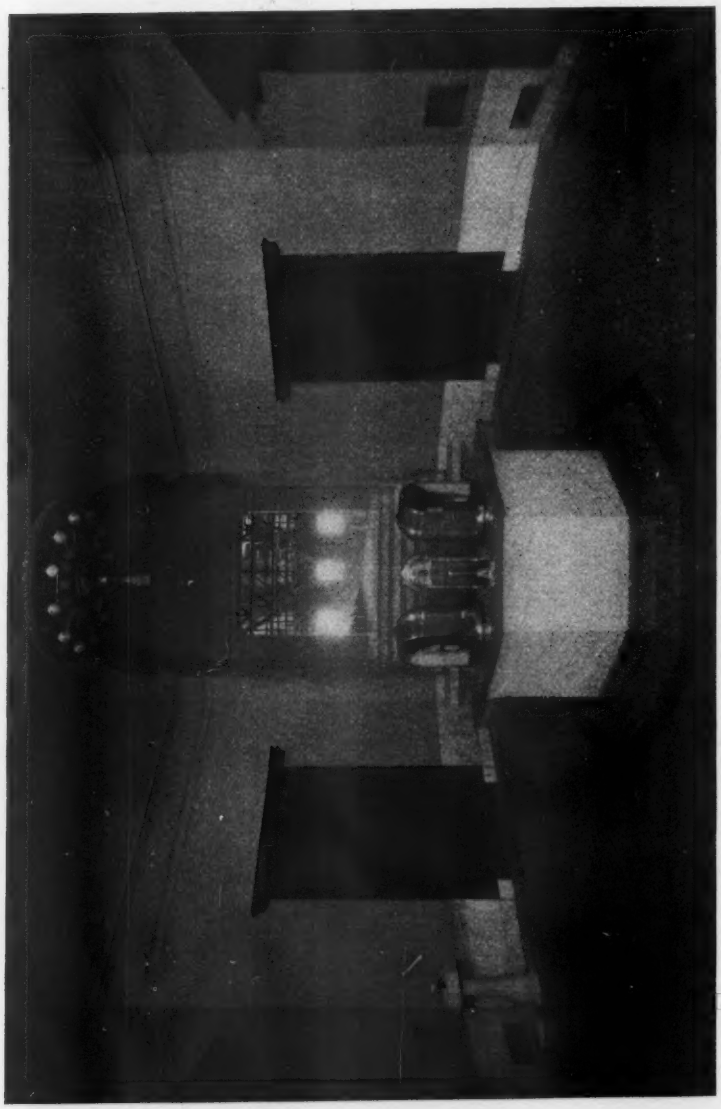
LOOKING DOWN INTO LOW SERVICE PUMPING PIT. (60 ft. deep)



INTERIOR PUMPING STATION. (Looking towards low service pumping pit.)

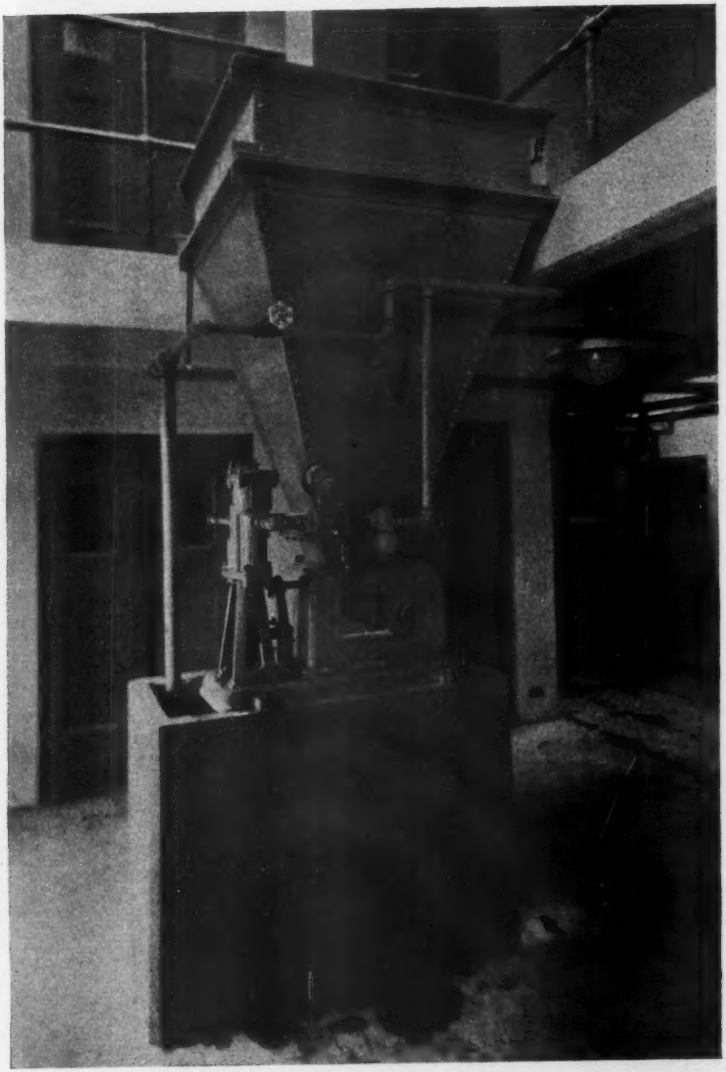


FRONT VIEW, COAGULANT HOUSE AND FILTER BUILDING.



LOBBY OF COAGULANT HOUSE. (Master control table in center.)

OPERATING FLOOR, FILTER BUILDING.



DRY ALUM MACHINE.

BACTERIOLOGICAL LABORATORY.

Discussion.

Morris Knowles.* Mr. Laboon has given us a most interesting presentation of a most thorough-going and latest-equipped filter plant. From personal experience the speaker can testify that it is a very difficult thing in a short presentation like this to make it clear to people what the plant is about, and I am sure he has done it very well. I am also just as sure that when we come to read this paper in the Journal we will find there are things we could not grasp in listening and about which we shall read with continued interest.

Two things do stand out. One is an exhibition of human engineering. More and more, as mentioned at various times, we are coming to appreciate that the engineer must not only be able to design well and to make good estimates and to explain thoroughly to a small group,—a board of directors or a city council,—but he must sell the idea, also, to that larger clientele, the public, or the voters, where it is for a municipality. I am sure we have all been very much interested in the successful methods which were used in this Wheeling campaign, and we can all profit by the experience. It will be a great deal of help to us if he will, even more extensively than he has done tonight in his paper, illustrate those methods which are so helpful.

The other point is this — I referred to it in speaking about another paper: The people in different parts of the country call for different kinds of water. As before stated, the people in New England are willing to put up with some colored waters, some of which are quite highly colored; although there is a growing realization that bleaching, largely by natural processes through storage, will improve this condition.

It was a common saying in the West that they would do with muddy water. Now we know that is no longer true, and as they come to want water free from mud they also will not put up at all with colored water. Perhaps it is due to the belief that if there be any discoloration in the water that it is impure. It is not easy to realize that it may be due to the dissolved color, which is not particularly disagreeable, and that it may not be due to silt or mud contained in the water.

Moreover, there has been, with this advance in filtration, an appreciation on the part of the public that they would like water that is softer. Where water is harder than 100 parts per million, or even less than that, people are coming to feel that they would like to have softer water. There is a growing belief that people are no longer satisfied with hard water because of the difficulties of washing, or sometimes even in making tea or coffee, and the general attendant domestic difficulties, with use of water for bathing, and so forth.

The author, as I understand this plant, has designed it to give softened water. It would be interesting if the author would now explain if the capacity of the sedimentation basins has been made measurably larger

*Consulting Engineer, Pittsburgh, Pa.

because of the desire to use softening; or are they no larger than they would be if they did not intend to use softening?

PRESIDENT TAYLOR. Can you answer that question, Mr. Laboon?

MR. LABOON. Yes, Mr. President. The basins have been designed to function as a part of an ordinary filtration plant, but due to the fact that we have installed a mixing chamber which is, we believe, well designed for the purpose of softening, at least as to obtaining velocities of a character which will produce the desired softening reactions, we can reduce our settling basin materially from what was accepted as good practice years ago. As you will recall, Mr. Hoover at Columbus has been obtaining excellent softening results in his tests with settling periods of two hours. While Mr. Hoover's experiments may be based on mechanical agitation, I think his results hold true more or less for the type of mixing chamber installed at Wheeling. Under the worst conditions, a Dorr thickener could be installed at Wheeling as a preliminary measure after the water has been mixed, to make the settling basins function efficiently as a softening plant. I do believe that when our proposed demonstration of the softening ability of the plant takes place we will be able to show that the basins are large enough, although we do not have to pass the State Board of Health in that respect.

PAUL HANSEN.* We are all very much indebted to Mr. Laboon for a paper of this sort. It is the kind of paper which is valuable to engineers in gaining information regarding existing plants, which information they may apply to the design of other plants.

There are two things about this plant that will be watched with very great interest. One is the false bottom for the filters, though that has been used before with apparently a good deal of success at Erie; and also the dry lime feed. The latter is an innovation and an advance in the art.

With reference to softening, I would like to emphasize Mr. Knowles' remarks, namely, that the general public is demanding higher and higher grades of water, and I think that during the next twenty years we can look forward to an increasing demand for softened water, just as during the last twenty or twenty-five years we have had an increasing demand for filtered waters.

At the Barton Harbor, Mich., water-softening plant it is found that a preliminary mixing with stirring devices for about an hour, followed by sedimentation in a Dorr clarifier, with about an hour's retention period, effectively removes over 90 per cent. of suspended matter from the water. The sedimentation basins following the clarifier, have a retention capacity of about eight hours, and I think they are too large. At the time of preparing designs we had no adequate precedent. In designing another plant it would be permissible to cut down the capacity of the plain sedimentation basins, following a Dorr clarifier to perhaps four hours.

*Of Pearse, Greeley & Hansen, Consulting Engineers, Chicago, Ill.

TASTES IN THE WATER SUPPLY OF MARQUETTE, MICH., DUE TO PHENOL WASTES.

BY PAUL HANSEN.*

[*Read September 9, 1925.*]

Marquette, Mich., has had an unusually long and trying experience with disagreeable tastes and odors in its public water supply, resulting from so-called phenol wastes from a charcoal by-products plant. As this case has been discussed in technical literature before, it may be well to give a brief historical outline of the occurrences of tastes and odors and the investigations that have been made, with a view to determining their sources and their remedies.

The water works of Marquette were first installed in 1870. At first the water was taken very near shore within the breakwater. Due to pollution and also to ice troubles, various modifications of the intake were made, until in 1901 a steel intake was laid, 800 ft. long, into a depth of 22 ft. of water. In about the same year the Cleveland Cliffs Iron Works established a charcoal iron furnace at Marquette. In conjunction with this installation there were built charcoal retorts and a charcoal by-products plant. From the by-products plant there were tarry and other wastes that soon caused disagreeable tastes and odors in the public water supply. The relation of water-works intake, discharge of wastes at the Cleveland Cliffs Iron Works, city sewer outlets, harbor breakwater, and shore configuration are shown in Fig. 1.

Professor Koenig's Investigations.

The first investigation with reference to tastes and odors in the public water supply was made early in 1904 by George C. Koenig, professor in the College of Mines at Houghton, Mich. He definitely ascribed the objectionable "tastes and odors to tarry substances, principally floating tar," escaping from the Cleveland Cliffs Iron Works plant. At that time more tar was being discharged into the lake than at present, and, in addition all so-called lime acetate liquors were wasted. Conditions at that time were such that the shore line and the bed of the lake near points where wastes were discharged were covered with a coating of tar. On the theory that there was always a southerly current along the shore line which would carry the wastes over the intake regardless of wind direction, and on the observed fact that tastes and odors occurred only when there was a wind from a northwesterly or northerly quarter, Professor Koenig concluded that the

* Of Pearse, Greeley & Hansen, Consulting Engineers, Chicago.

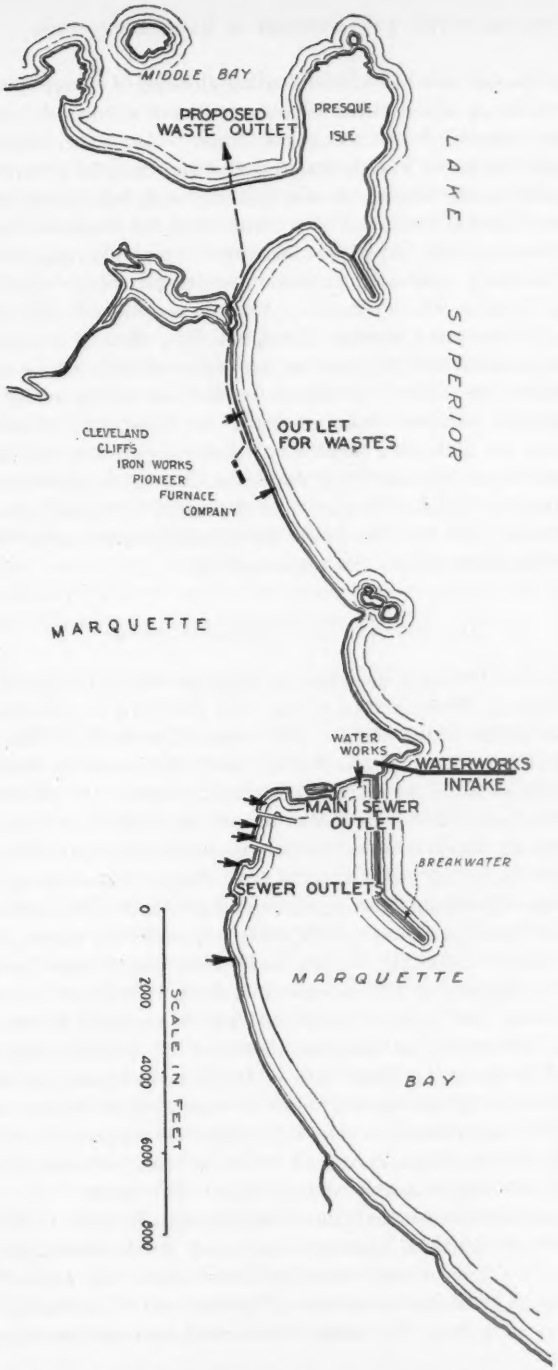


FIG. 1.—PLAN SHOWING LAKE FRONT OF MARQUETTE, MICHIGAN.

trouble must be due to wind-carried floating globules of tar and not to substances in solution, which latter he reasoned were adequately diluted to dissipate any tastes before reaching the intake. As further confirmation of his theories, Professor Koenig stated that when the lake is covered with ice, tastes rarely occur because the wind cannot reach floating tar globules.

Professor Koenig considered the removal of tar from the wastes by centrifugal means or by filtration. Because of the wide range of specific gravity of the tarry substances he recommended filtration. He proposed a process of filtration which comprised treating the waste liquors with fine charcoal and subsequent passage through a filter of sand or cinders. It was further proposed that the charcoal, impregnated with tar, be recovered and used under the boilers. A filter in partial conformity with Professor Koenig's recommendations was later built, but apparently it was inadequate. There are little data available to indicate just how the filter was built and how it was operated, but doubtless the area of about 500 sq. ft. was altogether too small. At any rate, it clogged so rapidly that it was soon abandoned, and the Company has generally maintained that this experience proved filtration to be impracticable.

Mr. Benzenberg's Investigations.

Shortly after Professor Koenig's investigation the city engaged George H. Benzenberg of Milwaukee to advise with reference to overcoming the tastes in the public water supply. He found as a result of observations through the ice that, contrary to general belief, there were no definite currents in the water of the bay which would tend to carry the phenol wastes from the Cleveland Cliffs Iron Works toward the intake, and he assigned this as the reason that the tastes were not generally observed when the bay was covered with ice for some distance from shore. This contrasted with the reasoning of Professor Koenig, namely, that the ice held back floating globules of tar which he assumed to be solely responsible for tastes. Laboratory tests made under Mr. Benzenberg's direction demonstrated that "creosoles" in solution, as well as suspended tarry matters, were responsible for the "creosote" or "smoky" taste and that the tar could be removed by filtration or otherwise, but that the dissolved substances could best be gotten rid of by dilution in pure water. Aeration, he found, had no effect, and though chemical substances might be employed to break down the taste-producing compounds so that they might be removed as suspended oils from the wastes, these chemicals would in turn introduce other and perhaps still more objectionable compounds into the wastes.

Mr. Benzenberg noted that the prevailing wind direction of Marquette for nearly every month in fourteen years prior to the investigation was either from a westerly or northwesterly direction and that westerly winds, if strong enough to induce a motion of the lake water, carried the wastes eastward and away from the intake, while north and northwesterly winds

caused the wastes to follow the shore southward and pass over the intake. The higher temperature of the wastes, he maintained, caused them to remain near the surface, thus favoring their transportation and dispersion by wind.

The report called attention to the danger of sewage pollution from the sewer outlets of the city, pointing out that northwest winds followed by south and southeast winds produced color and turbidity in the water supply, indicating the probability of sewage pollution. Muddy water from Carp River may also have had something to do with this; though it is not mentioned in Mr. Benzenberg's report.

To avoid sewage pollution and "creosote" wastes, Mr. Benzenberg recommended an intake extending out to a depth of water below the influence of wave action, which depth he placed at 55 ft. or, preferably, 60 ft.; this to be accomplished by an extension approximately 2 100 feet long to the then existing intake and in a line practically due east.

To test the feasibility of eliminating tastes by an extension of the intake, an experiment was conducted in the fall of 1905 with a $\frac{3}{4}$-in. suction pipe extending out into the lake 3 500 ft. and into 70 ft. of water. It appears that tastes were distinctly observable in the water so obtained, but considerable doubt was cast on the conclusiveness of this test on account of the possibility of leaks in the pipe line near shore.

Mr. Coleman's Report.

In 1906 Clarence Coleman, Civil Engineer, in a report dealing mainly with the protection of the Presque Isle Boulevard against damage by storms, also considered the contamination of the public water supply. Mr. Coleman, like Mr. Benzenberg, recommended the extension of the intake and laid special stress upon the necessity of avoiding sewage contamination. To determine the best point for an intake, he recommended the examination of samples, particularly from the bottom, within a reasonable radius of the existing point of intake. Following this suggestion, Dr. McCracken, then teacher of chemistry at the State Normal School at Marquette, obtained a number of samples within a wide radius of the existing point of intake. These samples were not tasted, but were submitted to a "color test" recommended by the "chemist in charge of the laboratory at Ann Arbor." In light of present knowledge, it is questionable if the color test was sufficiently sensitive to detect quantities of phenol wastes obvious to the taste.

As carried out, this investigation showed that "creosote in appreciable quantities did not extend far from the mouth of the existing intake except close to the bottom of the lake." (This is at variance with later observations which show that tastes predominate near the surface.) Very few samples beyond 1 000 ft. from the old point of intake showed more than the faintest trace of creosote, according to the report.

Though the Water-Works Committee recommended an extension of the intake, it was not carried out at this time.

Mr. Hering's Investigation.

In the autumn of 1909 Rudolph Hering was engaged to spend a day in Marquette and review the water supply problems. He had no opportunity to study the problem but, on the basis of information given him, summarized the situation as follows:

(1) Presque Isle is geographically the best site for an intake,
(2) An extension of the existing intake into 70 ft. of water would in all probability furnish a satisfactory water supply for a considerable term of years, and
(3) Conditions favoring location of an intake are subject to change by acquisition of new industries and construction of additional sewers and sewer outlets and that these considerations implied further changes and ultimate purification.

The Board of Fire and Water Commissioners Recommended Extension of Intake.

Early in 1910 the Board of Fire and Water Commissioners prepared a report in printed form. This report reviewed former investigations and set forth comparative estimates of cost of an extension of the existing intake into 70 ft. of water and a new intake off the northerly end of Presque Isle and extending eastward from Black Rock. These estimates of cost were made by the Duluth Engineering Company. In round numbers the first cost of the Presque Isle project was $248 000, with total annual charges of $16 000, whereas an extension of the existing intake involved a first cost, according to the estimates, of $63 000 and total annual charges of $5 000. In view of these estimates, and uncertainty of the complete success of the Presque Isle project, the majority of the committee favored an extension of the existing intake.

Mr. Johnson's Investigations.

On June 17, 1910, George A. Johnson, then of the firm of Hering and Fuller of New York, rendered a report, after a study of the water supply situation, with special reference to its sanitary quality, the investigation being apparently inspired by the presence of typhoid fever in the city. Mr. Johnson strongly endorsed the recommendation of Messrs. Benzenberg, Coleman and Hering, namely, that the existing intake be extended into 70 ft. of water. The Presque Isle project was not favored because there was little evidence to indicate that an intake off Presque Isle would yield a water of materially better physical or bacterial characteristics than could be obtained to the eastward of the existing intake in 70 ft. of water.

To remove from the supply, as then obtained, any danger to health, Mr. Johnson recommended the installation of means for applying hypochlorite of lime to the water.

Intake Extended After Favorable Popular Vote.

In May, 1910, while Mr. Johnson's investigations were under way, a bond issue was submitted to a vote of the people in a form that permitted a choice between an intake on Presque Isle and an extension of the existing intake. The vote was strongly favorable to the latter alternative.

A contract for an extension to the intake was awarded in June, 1911, and the work was completed in the spring of 1912. The length of extended intake is about 2 300 ft. and consisted of 36-in. cast-iron pipe (see Fig. 1).

Period of 1912 to 1920.

From 1912 to 1920 there was little agitation with reference to creosote tastes in the water supply, though officials state that complaints of tastes were received whenever the wind was from a northwesterly direction. However, the improvement resulting from the extension of the intake apparently greatly minimized the tastes and odors.

New Efforts to Stop Creosote Tastes.

In December, 1920, the city officials entered upon a determined effort to rid the water supply of objectionable tastes and odors. The company at this time maintained that there had been no objectionable tastes and odors except on one or two occasions of short duration during the winters of 1919 amd 1920 when "the lake was covered with ice as far as the eye could reach." (Note this statement in contrast with Prof. Koenig's and Mr. Benzenberg's references to the effect of ice.) The company's representatives did state, however, that they had frequently noticed tastes which they ascribed to the chlorine which was being applied to the public water supply.

Major Rich's Investigations.

In February, 1921, Major E. D. Rich, State Sanitary Engineer, was induced to visit Marquette and investigate the water supply. In February, 1921, he submitted a report upon the objectionable tastes in the water supply. Briefly summarized, Major Rich's comments were as follows:

(1) The tastes are probably intensified by the chlorine applied to the water supply, though chlorine was not being added in sufficient quantity to produce of itself a taste.

(2) There is a possibility of leakage in the joints of the intake line which would admit water from near shore.

(3) Though the average quantity of chlorine applied is unusually small, the amount applied during periods of low pumpage may be sufficient to produce tastes.

(4) Filtration of wastes through coke or cinders would remove some of the taste-producing subtances, but the area of beds would be large — roughly, about one acre for 30 000 gal. per day.

(5) In the light of experience elsewhere, removal of tastes by chemical treatment seems out of the question.

(6) Discharging wastes into the city sewers might through biological action break up the taste-producing compounds, as was observed at the sewage testing station at Milwaukee.

(7) The wastes might be pumped to an outlet in the lake north and west of Presque Isle where there would be no possibility of them reaching the intake.

Investigations by Messrs. Hommon and Brockway.

In March, 1921, Mayor Clark obtained the assistance of the United States Public Health Service and H. B. Hommon, Associate Sanitary Engineer, was detailed to visit Marquette. At the suggestion of Mr. Hommon, W. C. Brockway, Assistant Engineer of the State Department of Health, was assigned to coöperate in the investigation. Following several days investigation a preliminary report was submitted, as follows:

(1) That the chlorine used for sterilizing the public water supply could not produce by itself tastes and odors in the water.

(2) That while the water supply drawn from the extended intake is generally of excellent physical and sanitary quality, yet the danger of occasional pollution from wind-blown sewage and from passing boats requires chlorine treatment, and

(3) That the tastes observed are unquestionably due to tarry and liquid wastes discharged from the Cleveland Cliffs Iron Works.

The report indicated that if evaporation of these wastes, suggested by Mr. Hommon, were not feasible, then more or less prolonged research would be required to determine what treatment might be applied to the objectionable wastes as a means of neutralizing or removing the taste-producing elements. Acting upon the suggestion of Mr. Hommon, the local officials attempted evaporation of the several wastes which were deemed solely responsible for the objectionable tastes and odors imparted to the public water supply. Messrs. Hommon and Brockway then renewed their investigations to determine if the two wastes proposed to be evaporated were responsible for the tastes and odors. On the basis of a number of taste experiments, they concluded that the taste-producing substances were encountered practically entirely in two wastes, namely, the tarry residue resulting from the evaporation of crude pyroligneous acid and the residue from the crude wood alcohol still known as No. 110 still. (These wastes will be referred to again later.)

The Shutdown from February, 1921, to March, 1922.

The effects of evaporating the wastes were not ascertainable at this time, owing to the fact that the Cleveland Cliffs Iron Works shut down in February, 1921, and did not start operations again until March 1, 1922, a period of somewhat over one year. The striking feature of this shutdown

was that no tastes whatever were observed in the water supply during the entire period, thus eliminating the contention, frequently made by the company, that the tastes were due to the application of too large quantities of chlorine. When the plant was again placed in operation, notwithstanding the fact that the two wastes above referred to were being evaporated, tastes in the public water supply reappeared on March 4, 1922, and continued during the major portion of the following two months. During the summer months of 1922, tastes were noticeable only occasionally, and during the month of August they did not occur at all. In the autumn, however, beginning in September, creosote tastes became quite frequent and were very persistent during the next three months.

Renewed Agitation to Eliminate Tastes in 1924.

In the early part of 1924, agitation was begun anew to get rid of the creosote tastes and odors, and in February of that year Messrs. Pearse, Greeley, and Hansen were employed to study and report upon the situation. In this connection they associated with themselves Dr. A. M. Buswell, to examine into the chemical phases of the problem.

Geographical Elements.

Before proceeding further with the discussion of the problem of eliminating tastes and odors, it might be well to indicate certain geographical relations. Marquette is in the northern peninsula of Michigan on the south shore of Lake Superior. An indentation of the lake shore known as "Marquette Bay" causes the city water front to have a generally north and south direction (see Fig. 1). The shore line is composed principally of two crescent beaches lying between the rocky promontories of Presque Isle north of the city and Light House Point, nearly opposite the center of the city. These physical features constitute a factor in the movement of taste-producing wastes toward the water-works intake, as will be discussed later.

The sewerage system is related to the problem under investigation in that the present method of disposing of sewage will become a greater and greater menace to the quality of the public water supply and, as will be shown later, the sewage may be utilized in solving the problem of removing taste-producing substances from the industrial wastes of the Cleveland Cliffs Iron Works. The main discharge of the sewers is just inside of the breakwater at a point shown on Fig. 1. The sewage thus must travel a more or less circuitous route to reach the intake. It is probably largely on this account that the raw water at the intake rarely shows the influence of sewage contamination. It may ultimately be necessary, however, as an adequate protection to the water supply to bring the sewage together at one point for treatment. This appears to be in the rather distant future.

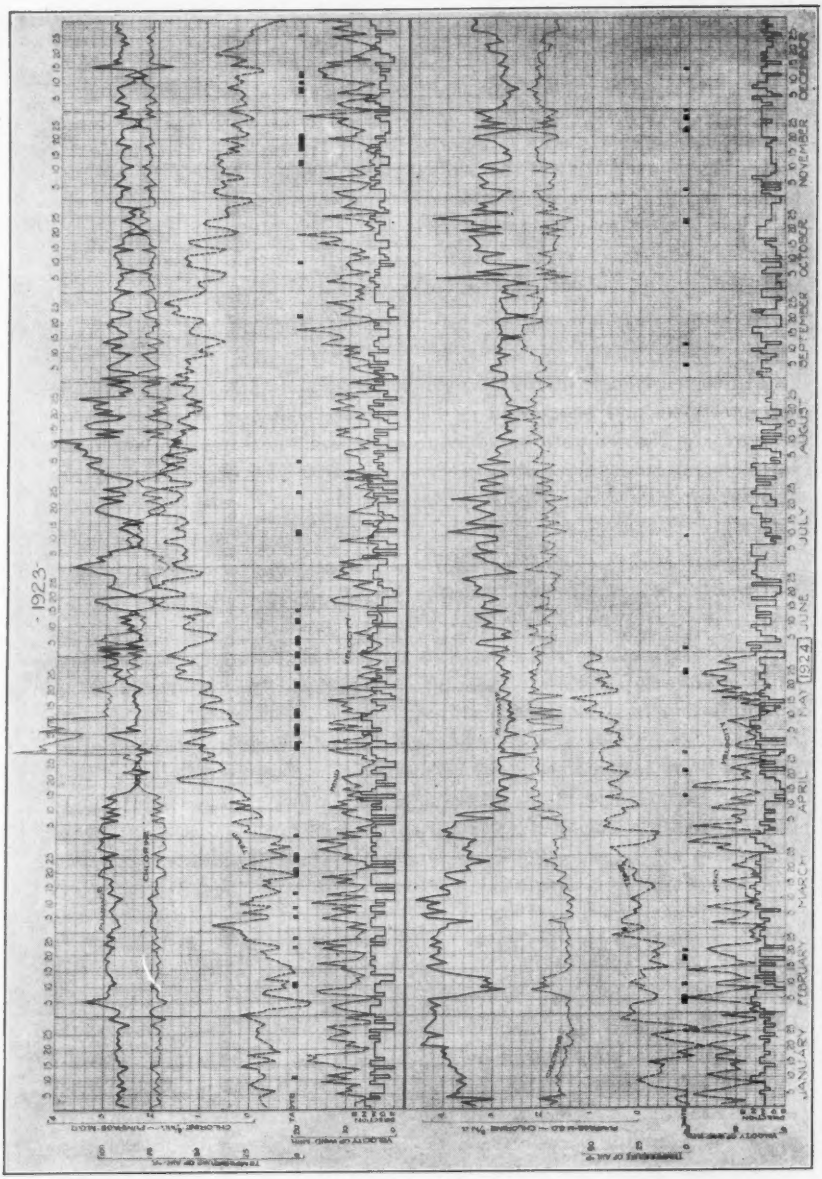


FIG. 2. — WATER PUMPED, CHLORINE APPLIED, AND BACTERIAL ANALYSES OF RAW WATER.

Features of the Public Water Supply.

The intake of the public water supply, as shown on Fig. 1, is about 3 000 ft. from shore and is in about 60 ft. of water. The water is taken through upturned elbows at a depth of about 56½ ft. below the level of the lake. Chlorine is added in very small quantities as the water emerges from the intake pipe into the suction chamber of the pumps. The normal dosage is about 0.17 parts per million. The present water consumption is between 3 500 000 gal. and 4 000 000 gal. per day.

Lake Superior water when not contaminated may safely be said to be among the best for public water supply of any in the world. It is crystal clear, practically free from mineral content that produces hardness, and free from tastes and odors, and in Marquette it would have these characteristics were it not for the contamination caused by industrial wastes from the plant of the Cleveland Cliffs Iron Works. The water pumpage, chlorine applied, and bacterial analyses of the raw water are summarized in Fig. 2.

Waste-Producing Processes at the Cleveland Cliffs Iron Works.

To further understand the character and influence of the wastes from Cleveland Cliffs Iron Works, some explanation of the process carried out in the charcoal by-products plant will be necessary. The processes are indicated diagrammatically on the flow sheet, Fig. 3. In this diagram, the flow of waste liquors is shown by heavy lines. The diagram must be read downward on the left-hand side of the central heavy line and upward on the right. This grouping was necessary in order to bring all the waste liquors to a central line.

Pyroligneous Acid.

The wood, consisting of ash and other deciduous varieties, after being cleaned and cut into proper lengths, is placed in charcoal retorts. The retorts are subject to heat from furnaces which drive off the volatile matter in the wood. This volatile matter is condensed and the condensed liquid is known as pyroligneous acid. Frequently, especially in winter, the "first cut" of pyroligneous acid is diverted into the southerly open drainage ditch referred to as the "east ditch." These discharges are made once in 18 or 20 hours. The volume of the "first cut" is said to be about 2 000 gal. A sample taken toward the last of a run of a first "cut" is a yellowish-brown liquor containing suspended matter apparently of a tarry nature. It has a very pronounced taste and odor of phenols, which can be plainly tasted in dilutions as great as one in 500 000. One observer could get a distinct taste in a dilution of one in 800 000 and a slight taste in one to 1 000 000. The dilution water was from the Chicago city water supply and contained a slight excess of chlorine, which may have intensified the taste to some extent, but this is comparable to conditions at Marquette. Crude pyro-

ligneous acid is a very complex substance, yielding a great variety of marketable compounds, the principal of which are creosote oil, tar, wood alcohol, acetic acid, and acetone.

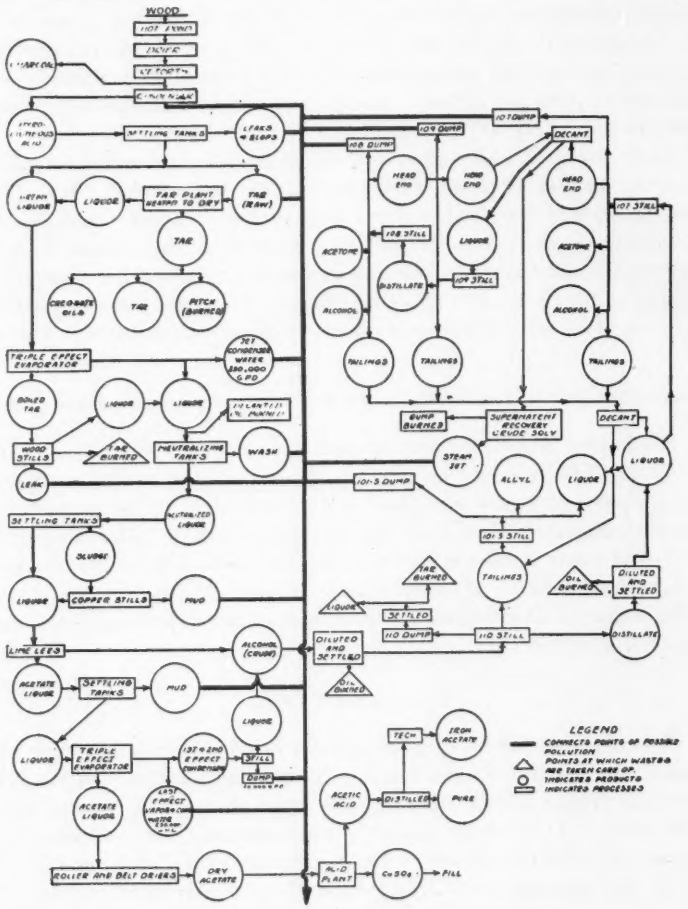


FIG. 3. FLOW DIAGRAM, CHARCOAL BY-PRODUCTS PLANT.

REMOVAL OF TARS.

The pyroligneous acid is first passed through a series of wooden settling tanks in which tarry substances are deposited. These settleable substances are drawn off and conveyed to the tar plant "where they are subjected to fractional distillation." Three products are obtained in this manner, namely, the lighter creosote oils, liquid tar, and pitch. No liquid wastes result from the operation at the tar plant.

Triple Effect Evaporators.

The supernatant liquor from the settling tanks, known as "green liquor," is conveyed to triple effect evaporators; the distillate from this process is condensed and constitutes the element from which further valuable products are obtained.

The residue from the triple effect evaporators is a tarry liquid and was discharged into the waste drains until April, 1921. This substance was formerly believed to be the sole cause of the tastes and odors in the public water supply. Undoubtedly it constituted by far the most troublesome of the wastes affecting the public water supply. It not only entered the intake directly, but caused deposits along the shore and in the lake bottom which for long periods yielded soluble products which were carried by the wind toward the intake. These tarry products are now evaporated nearly to dryness and the tar is burned under the boilers.

The condensation of the distillate is usually effected without the entrance of taste-producing substances into the condenser water, but certain derangements may take place which may cause passage of some taste-producing wastes into the condenser water.

Recovery of Acetic Acid.

The condensate from the triple effect evaporators is conveyed to decanting tanks where floating light oils are decanted and burned under the boilers. The residue goes to neutralizing tanks where it is treated with lime for the purpose of neutralizing and combining the acetic acid. The neutralized liquor is drawn off and conveyed to settling tanks. There is left behind in the neutralizing tanks a gritty residue consisting mostly of gravel, sand, unburnt limestone, and impurities from the lime. To free these tanks of the strong fumes of acetic acid before men can enter them to remove the gritty residue, they must be washed out. These washings amount to about 10 000 gal. per day and contain some phenol wastes — a fact not hitherto recognized.

The neutralized liquor is conveyed to stills known as "lime lees" for distilling off crude 45 per cent. wood alcohol, and the concentrated acetate of lime liquor remains. The acetate liquor is evaporated down in triple effect evaporators. The vapors are condensed and passed through a fractionating still from which further alcohol-containing liquors are recovered. There is a phenol-containing waste from this fractionating still amounting to about 30 000 gal. per day. This waste, like the washings from the neutralizing tanks, has not been hitherto recognized as a taste-producing waste, though as a matter of fact it produces tastes in dilutions as great as 1 to 500 000.

The concentrated acetate liquors are dried and treated for the recovery of acetic acid. No further liquid wastes result from this process.

Liquor	Dilutions																																					
	Undiluted				1 to 1000				1 to 2500						1 to 25,000						1 to 250,000								1 to 500,000										Tap Water	
					Distilled Water				Distilled Water				L. Superior Water		Distilled Water				L. Superior Water		Distilled Water		L. Superior Water				Mich. Water		Distilled Water				L. Superior Water				Mich. Water	
	Taste		Odor		Taste		Odor		Taste		Odor		Taste		Odor		Taste		Odor		Taste		Odor		Taste		Odor		Taste				Taste		Odor		Taste	
	Cold	Hot	Cold	Hot	Cold	Hot	Cold	Hot	Cold	Hot	Cold	Hot	Cold	Hot	Cold	Hot	Cold	Hot	Cold	Hot	Cold	Hot	Cold	Hot	Cold	Hot	Cold	Hot	Cold	Hot	Cold	Hot	Cold	Hot	Cold	Hot	Cold	Cold
First cut wood retorts	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	?
Leakage from wood stills (tar)	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	?	?	?	?	?	?	?	?	+	?	?	?	?	?	?	?	+	?
Wash water from neutralizing tanks	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	?	?	?	?	?	?	?	?	+								?	–
Acetate settling tanks	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+																		
Acetate mud	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	?	?	?	?	?	?	?	?	+	?	?	?	?	?	?	?	+	?
Copper still mud	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	?	?	?	?	?	?	?	+	+
Dumps from acetate still	+	+	+	+	+	+	+	+	+	+	+	+					+	+	+	+					+	+	–	+	+	+	+	+	+	?	–	+	–	–	–	–	+	
Condenser water acetate evaporators	+	+	+	+	+	+	–	+	–	?	–	–	+	+	–	+	–	–	–	–	–	?	–	+															
Dumps 110 still	+	+	+	+	+	+	+	+	+	+	+	+					+	+	+	+					+	+	+	+	+	+	+	+	+	?	?	?	+	+	+	–	+	+
Dumps 109 still	+	+	+	+	–	–	–	–	–	–	–	–																												
Dumps 107 still	+	+	+	+	+	+	–	?	–	–	–	–																												
West ditch	+	+	+	+	+	+	–	?	–	–	–	–																												
East ditch	+	+	+	+	?	+	?	+	–	–	–	–																												

Note:–

Plus sign (+) indicates taste is noticeable.
Minus sign (–) indicates taste is not noticeable.
Question mark (?) indicates that presence of taste is uncertain.
Blanks indicate that no tests were made.

TABLE 1. LABORATORY OBSERVATIONS ON TASTES AND ODORS FROM CLEVELAND CLIFFS IRON WORKS.

Refining Crude Wood Alcohol.

The crude alcohol goes to a still known as "110 still," which produces a partially purified 95 per cent. alcohol. The dumps from this still, amounting to about 6 000 gal. per day, constitute an important waste formerly regarded by Hommon and Brockway as one of the two wastes then believed to be entirely responsible for tastes in the water supply; the other being the tarry substances from the first triple effect evaporators. These wastes, which were impregnated with tarry substances, can be tasted in dilutions of 1 to 500 000, and even greater.

Summary of Taste-Producing Wastes.

To the tarry wastes and dumps from the crude alcohol still, as already noted, we have now to add the first cut of pyroligneous acid from the charcoal retorts, acetate muds, wash water from neutralizing tanks, dumps from the acetate fractionating stills and, occasionally, condenser water, amounting in all to approximately 50 000 to 60 000 gal. per day.

There are a number of other processes that follow No. 110 still, but none of these results in taste-producing wastes of importance.

The summary of laboratory tests on the taste-producing power of various wastes is shown in Table 1.

Possible Means of Eliminating Tastes.

In the light of previous investigations at Marquette, local conditions and experience elsewhere, it was concluded that a solution of the difficulty would be found in one or more of the following ways:

(1) To establish a new intake at a point beyond the reach of taste-producing wastes,
(2) The diversion of the creosote wastes to a point of discharge into the lake where they will be unable to reach the present point of intake,
(3) Treatment for absorption of the taste-producing wastes at the Cleveland Cliffs Iron Works,
(4) Treatment of the water supply so as to eliminate tastes when they occur,
(5) Mixture of wastes with the city sewage with means for maintaining the sewage and wastes in contact long enough for biological activity to break up the taste-producing compounds.

These will be discussed briefly in the order given above.

Effect of Establishing a New Water-Works Intake.

With reference to the establishment of a new intake at a point beyond the reach of the creosote wastes, it is necessary to consider the dispersion and travel of phenol wastes after discharge into Lake Superior. From evidence and observations, it appears that tastes in the water supply may

develop anywhere within Marquette Bay from the north side of Presque Isle practically down to the mouth of Chocolay River, and anywhere within reasonable reach of any possible intake that might be located in Marquette Bay. There was some testimony to indicate that tastes in the water of the lake had been detected as far away as Partridge Island, one and one-half miles westerly of Presque Isle, and on Granite Rock, nine miles north of Presque Isle.

During one of the trips of inspection, when there was a gentle wind from the south, the tastes were followed for fully a mile north of Presque Isle, and it was possible to estimate that under the influence of the wind-induced currents, the wastes were travelling at the rate of approximately one-quarter mile per hour.

Theoretical Considerations on Travel Phenomena of the Wastes.

Some theoretical computations were made on the basis of assumed velocities of wind-induced currents and assumed taste-producing powers of the wastes. The results of these computations are shown in Figs. 4A–4D. Various angles of dispersion of the wastes were considered, which are believed to represent the range actually obtaining with persistent winds in one direction. From these studies it will be observed that the distance to which concentration of wastes capable of producing taste are carried, are greater for low wind velocities than for high wind velocities. With wind velocities of about $\frac{1}{4}$ of a mile per hour, the tastes may be detected anywhere from 6 000 to 10 000 ft. from the point of discharge. Actually they have been detected farther than this under the influence of gentle winds. There are, of course, considerable deviations from these theoretical considerations, due to wind changes; also the configuration of the shore line influences the travel of the wastes. As will be noted from Fig. 1, any wind blowing from a northerly or a northwesterly direction will cause the taste-producing substances to follow along the shore line and out toward the intake. It will be observed that the present intake is in a relatively unfavorable position with reference to the present point of discharge of the taste-producing wastes. While the diagrams in Figs. 4A–4D do not show precisely what takes place, they do help to visualize the movement of wastes.

The Influence of Temperature on Movement of Wastes.

The influence of temperature has a marked effect upon the travel of taste-producing wastes. As already indicated, there is a great increase in the frequency of tastes in the water supply in the winter, as compared with summer months. This is in part a result of winds prevailing from a southerly quarter in the summer, but it is primarily due to the relative warmth of the surface layers of water as well as the high temperature of the waste waters from the Cleveland Cliffs Iron Works. In winter time, on the

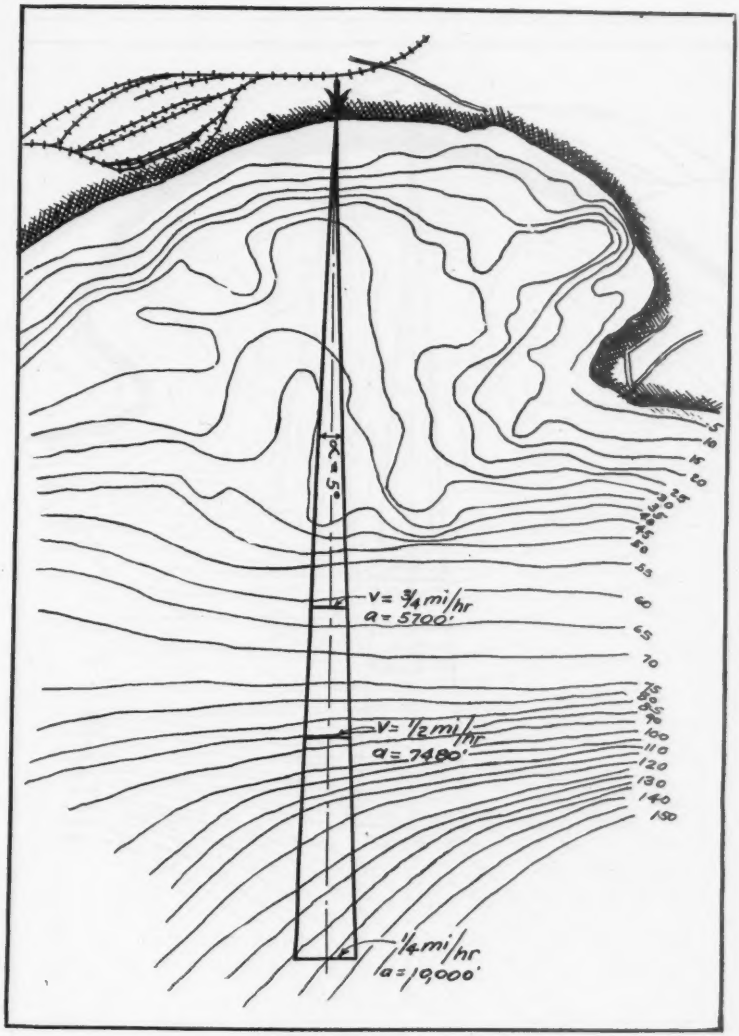


FIG. 4A. — EFFECT OF LAKE CURRENTS ON TASTE-PRODUCING WASTES.

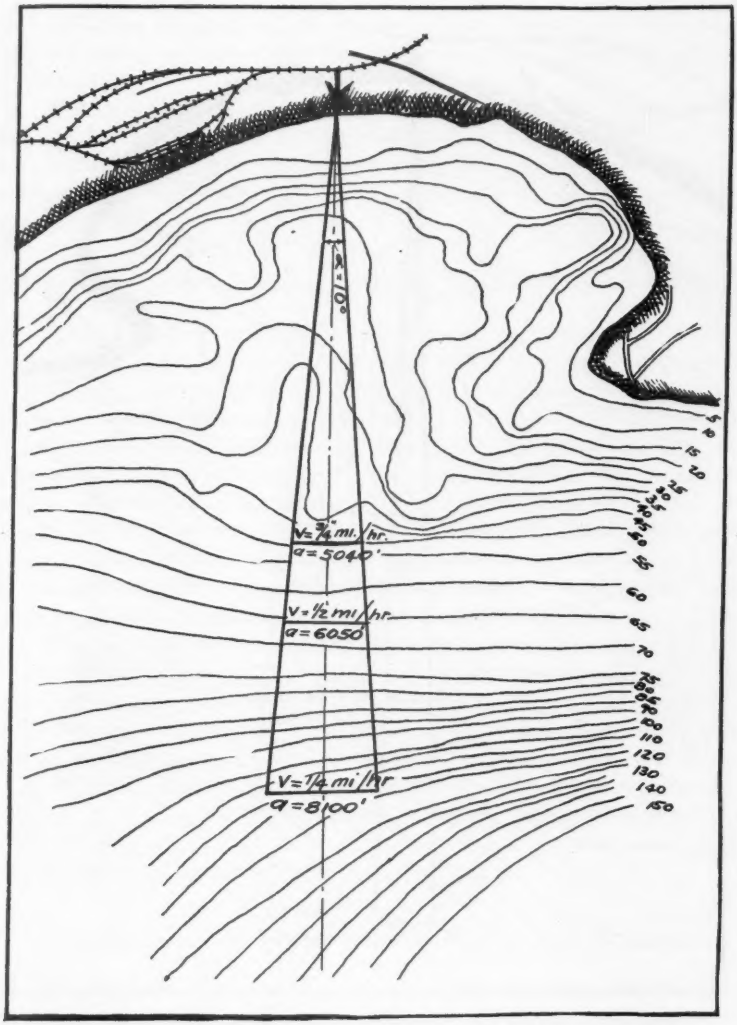


FIG. 4B. — EFFECT OF LAKE CURRENTS ON TASTE-PRODUCING WASTES.

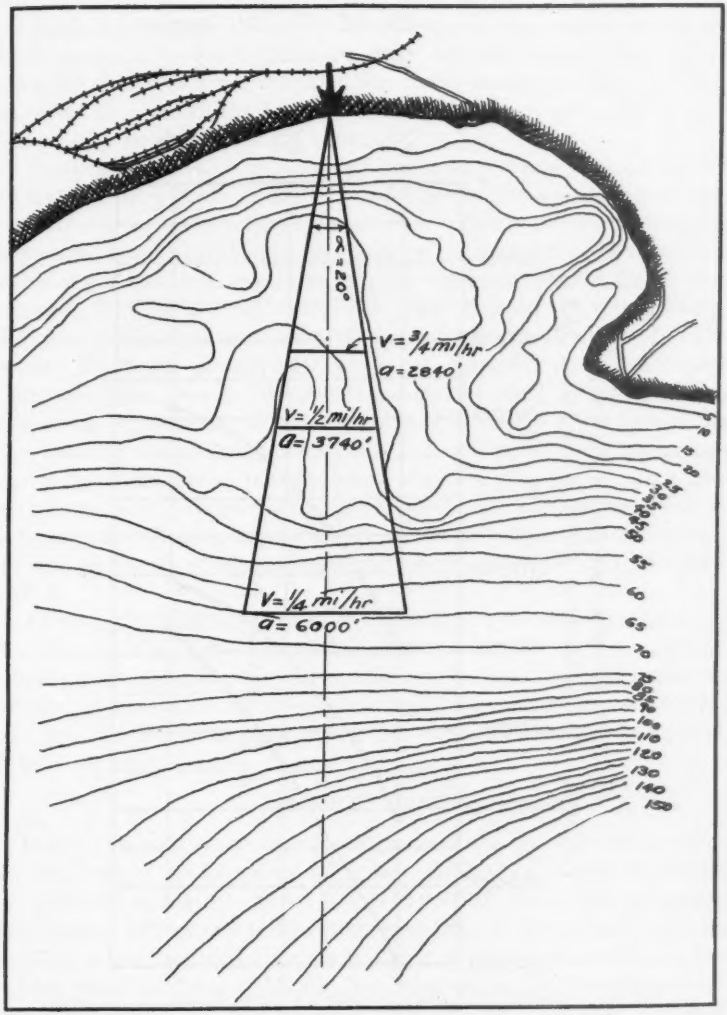


FIG. 4C. — EFFECT OF LAKE CURRENTS ON TASTE-PRODUCING WASTES.

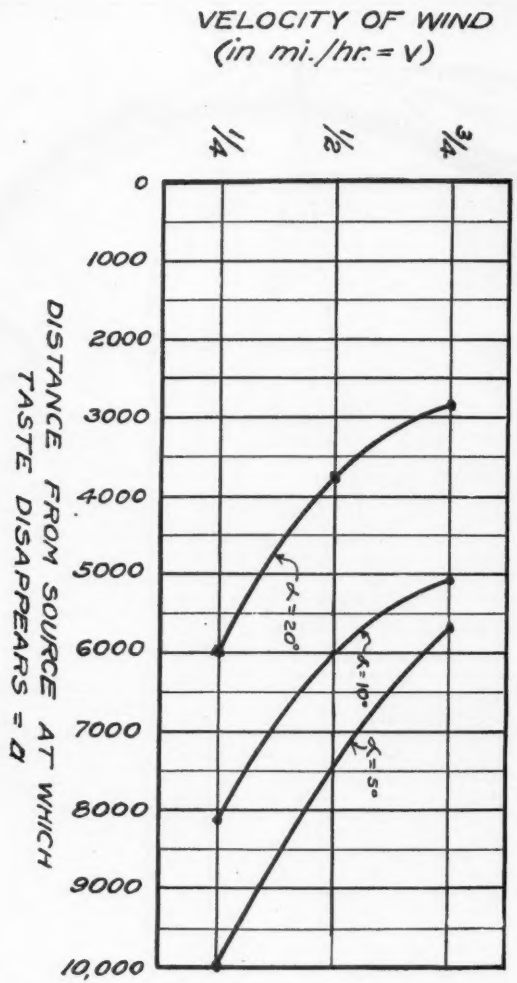


FIG. 4D. — EFFECT OF LAKE CURRENTS ON TASTE-PRODUCING WASTES.

other hand, the wastes are chilled by floating ice or by a very cold atmosphere down to the temperature of maximum density of about 34° F., at which temperature they freely commingle with the waters below. During the autumn overturn in October and November, there is likely to be a marked prevalence of tastes. At this period, the surface waters are cooled down to lower temperatures than the underlying water, which causes the surface waters, including the cooled wastes, to sink. During this period of overturn the mixing of upper and lower strata of water is more positive and active than in winter.

The suggestion has been advanced that if an intake could be extended into water of such depth as not to be affected by atmospheric conditions, all troubles from tastes might be overcome. This is the depth at which the pressure is sufficiently great to compress water of normal temperature for that depth to a density greater than the maximum density due to temperature. For the general latitude of Lake Superior in this country, Whipple sets this depth at about 50 ft. for small quiescent lakes. In Lake Superior the depth of stagnation would be materially greater than this theoretical depth, because of currents induced by wind movements. Inshore winds, for example, move large volumes of surface water toward the shore, creating a corresponding undertow outward which tends to displace some of the water below the theoretical depth of stagnation. Just how deep this disturbance would extend is difficult to say, without some elaborate temperature studies under various wind and temperature conditions. However, the depth of circulation of the Great Lakes has been estimated at 200 ft.

All things considered, it appears that within practicable limits there is no place in Marquette Bay where an intake can be located with any assurance that objectionable tastes will be materially lessened either in frequency of occurrence or intensity as long as the wastes from the Cleveland Cliffs Iron Works continue to flow into Marquette Bay at the present points of discharge.

Diversion of Wastes.

It would be rather more practicable to divert the taste-producing waste from the plant of the Cleveland Cliffs Iron Works to an outlet in Middle Bay, as shown on Fig. 1. About 50 000 to 100 000 gal. per day of wastes would have to be pumped to this point of outlet. This method would be reasonable in cost and probably effective, but would be objected to by the residents along the shore of Middle Bay, who use the Bay extensively for boating and fishing and, to some extent, for bathing. Consideration was also given to pumping to Middle Bay the entire wastes from the Cleveland Cliffs Iron Works, amounting to about 9 000 000 gal. per day. This would involve a considerable element of cost as compared with other methods, and would be subject to violent objections on the part of persons owning property on Middle Bay.

Treatment of Wastes at Cleveland Cliffs Iron Works.

Several methods for treating the wastes at the Cleveland Cliffs Iron Works were considered. One was a treatment of the taste-producing wastes by excess quantities of chlorine, which would have the effect of breaking down the phenol compounds responsible for the objectionable tastes. It is to be noted at this point that while small quantities of chlorine intensify the taste-producing qualities of wastes through the formation of chlorophenols, an excess treatment of chlorine will break down the phenols. This

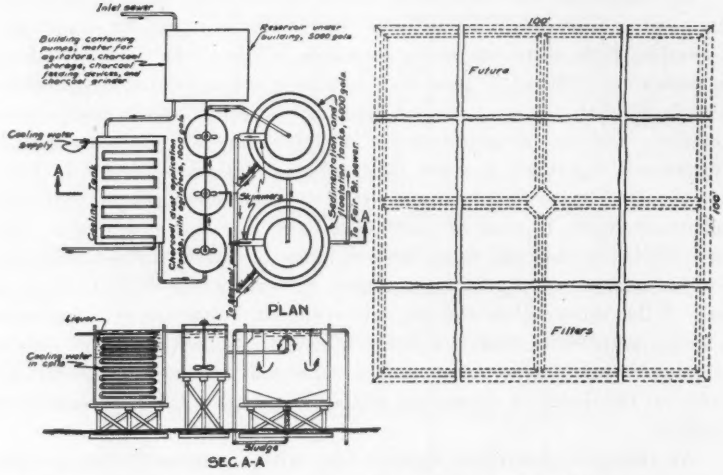


Fig. 5. — Plan of Plant for Partial Treatment of Wastes at Cleveland Cliffs Iron Works.

method on a laboratory scale proved effective, but the quantity of chlorine required was very large, amounting to about 1 000 lbs. per day, an amount which was regarded as prohibitively expensive.

Another method of treating the wastes at the plant comprised cooling, mixing with powdered charcoal (now a waste product in the plant), sedimentation and, possibly, filtration. On a laboratory scale, this process without filtration was found to be effective in clarifying the wastes, and reduced the taste-producing powers by about 50 per cent. Figure 5 shows in diagrammatic form the proposed plant for treating the taste-producing wastes at the Cleveland Cliffs Iron Works. This plant is based on the assumption that the total volume of wastes will not exceed 48 000 to 50 000 gal. per day. The temperatures of the wastes are reduced in the cooling tank from about 180° F. to about 80° F., with cooling water at 50° F. The cool liquor is mixed with charcoal in mixing tanks equipped with mechanical agitators and having a retention period of about 1½ hours. The sedimentation and skimming tanks have a retention period of about six hours.

Removal of Tastes by Mixing Wastes with City Sewage.

It is proposed to convey the effluent from this treatment to the city sewers where it will be mixed with city sewage and be retained in a tank at the outlet of the sewers. This tank, shown diagrammatically in Fig. 6, is a reaction tank and not a sedimentation or septic tank. A design is proposed which may permit its later conversion into an activated sludge plant. The retention period in this tank will be about eight hours for the mixed sewage and wastes, which will reduce the waste-producing properties

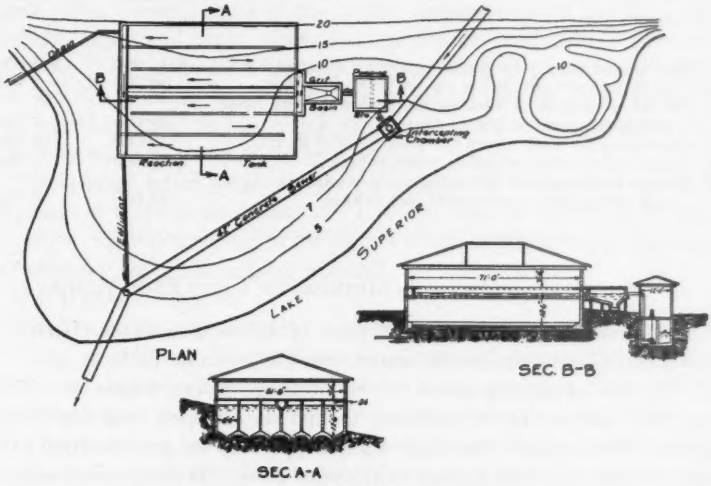


Fig. 6. — Plan and Sections of Reaction Tank.

by 50 per cent., making a total reduction of about 75 per cent. The ratio of wastes to sewage is about one volume of wastes to 15 volumes of sewage.

The mixed sewage and wastes will be discharged inside the breakwater (see Fig. 1) so that the travel of the wastes before they can reach the intake must be first southward and then northeastward. It is very rarely that a northerly wind is followed by a southwesterly wind, therefore, with this arrangement, it is improbable that taste-producing wastes in sufficient concentration will reach the intake except at very rare intervals.

Excess Chlorine Treatment of Water Supply.

Some consideration was given to treating the public water supply with an excess of chlorine sufficient to break down phenol compounds, the excess chlorine in turn to be neutralized by sodium thiosulphate. While this process theoretically would be feasible and reasonably economical, it was not deemed advisable to attempt it, without preliminary experiments on a large scale, at the water-works plant. As this process had no economical

advantage over partial treatment of wastes at the Cleveland Cliffs Iron Works, supplemented by mixing with the city sewage and discharged within the breakwater, it was not deemed advisable to go to the expense of carrying out large-scale experiments.

TABLE 2.

MARQUETTE, MICHIGAN.

Summary of Costs of Several Methods of Removing Tastes from Public Water Supply.

Scheme.	Installation Cost.	Annual Cost.
1. New Water Supply Intake northwest of Presque Isle..	$446 000	$35 000
2. Conveying taste-producing wastes to Middle Bay.....	22 595	1 880
3. Partial treatment of taste-producing wastes at plant and conveyance to Middle Bay.....	28 000	3 780
4. Conveying all wastes from the plant to Middle Bay...	148 000	16 000
5. Excess chlorination of public water supply.....	38 500	7 265
6. Partial treatment of taste-producing wastes at plant, and subsequent contact with city sewage.....	45 050	6 340

COMPARISON OF SEVERAL METHODS OF TASTE ELIMINATIONS.

A summary of the estimated costs of different methods of removing tastes and odors of the public water supply is given in Table 2.

In view of the opposition to the discharge of any wastes into Middle Bay, this solution of the problem, though the cheapest, was discouraged. Excess chlorination of the public water supply was the next cheapest in first cost, though somewhat high in total annual costs. As already indicated, the effectiveness of this method is still uncertain, and it no doubt will be confronted with many practicable difficulties.

Partial treatment of the taste-producing wastes at the Cleveland Cliffs Iron Works, with subsequent contact with city sewage, would appear to be practicable, effective, and a reasonably economical treatment. Though no definite recommendations were made, all the factors in the case seem to point to this as the logical solution. As the investigation was followed by summer weather, with consequent absence of tastes in the water supply, and by dull business at the Cleveland Cliffs Iron Works, nothing definite has yet been done toward carrying out any of the plans developed in the preliminary investigation.

DISCUSSION.

MORRIS KNOWLES.* The author has given us an interesting story of a growing form of trouble to public water supplies, which perhaps has not yet become a menace in New England but certainly has become common in some other parts of the country with which some of us are familiar. As has been said, while it is not as dangerous to public health as sewage pollution, it is certainly distasteful, offensive, and unpleasant. And in many cases indirectly it leads to just as grave dangers to the public health; because, with the avoidance of the public supply, when it has these objectionable tastes and odors, people turn to supplies that are nowhere near as healthy. That, after all, is the serious thing which confronts such public water supplies from the health standpoint. If people, for some reason or other, have objection to the water supply, they turn to something else which looks all right but may be very serious.

The speaker refers to a very unique method of treatment, and as I understand it there is no occasion — I believe that is correct, is it, Mr. Hansen ? — there is no occasion for the use of quenching water in the making of charcoal, as in the making of coke?

MR. HANSEN. No, sir.

MR. KNOWLES. And in that respect the conditions differ from another form of pollution of about the same material, brought about in a different way, namely, the making of coke. This is common in our part of the country and in the South, and also somewhat along the Great Lakes.

We have recently had examples where people have become lulled, as the author has said, by having the trouble only recurrently. That was true in the case of Tuscaloosa, Ala., on the Black Warrior River, where occasionally there had been a recurrence of tastes and odors, and then with the increase in the flow of the river, and by the cessation of the processes of manufacture, it was not as noticeable and the people forgot about it.

We find that there is a growing feeling on the part of industry that it has contributed something to the trouble with the streams, and therefore it should do something to relieve it. There was a meeting in Pittsburgh some time ago in which representatives of the public health officials of the country and the manufacturers of the country sat down around the table and talked about this thing and tried to find the solution. The manufacturer has taken a prominent part, and I was very glad to see this spirit in Alabama, although there is not, at the present time, the probability that there is any trouble caused at Tuscaloosa on the Warrior River by wastes from Birmingham, Bessemer, and Ensley; there is the attitude on the part of the manufacturers that, whenever and if there should be any such trouble, they stood ready to do their share to do what they could to prevent such taste and odor.

*Consulting Engineer, Pittsburgh, Pa.

But the trouble at Tuscaloosa was caused a few miles above, by a by-product coke-oven plant at which the wastes entered the stream. The best thing we know and advised is to use the wastes in quenching the coke. There is some discussion as to whether that is altogether wise from the commercial standpoint. There are some who will say that it injures the quality of the coke. So far as is known, however, at the present time, about the only detriment is one of color, and the people who have been used to the lustrous coke object to the dull coke which is occasioned by the use of these forms of waste in quenching. Again, if the coke is sold for domestic purposes and is stored in a cellar which is not thoroughly aired, there may be some odor come up through the house. Both of those are not general, but at the same time they are noticed and they are to be reckoned with because the trade is a cautious buyer and pays attention to such items. But on the whole, the only known and successful method at the present time to get rid of such tastes and odors — and that is the one which has been practiced — is to use the wastes, and all of them, by applying to the coke in the cars when it is red hot, for the purpose of quenching it.

LAWRENCE WATER SUPPLY — INVESTIGATIONS AND CONSTRUCTION.

BY MORRIS KNOWLES,* MYRON MANSFIELD,† AND PATRICK NUGENT.‡

INTRODUCTION.

The City.

The city of Lawrence, the second largest in Essex County, is located on the Merrimac River in the northeasterly part of Massachusetts near the New Hampshire boundary line. The city is small in area, covering only slightly more than seven sq. miles, and is compactly built. It has little undeveloped territory, this being mainly on the southerly side adjacent to Andover and North Andover. It has 112 miles of streets, about one-half of which are paved. The industrial section of the city is along the Merrimac River, and along certain portions of the Spicket River, particularly near the Methuen line. This naturally resulted from the early development of the water power in these rivers. The main business and commercial district is located largely on the north side of the river along Essex and Common streets and along Broadway at right angles thereto. These, together with the industrial areas, comprise the fire risk districts. The major portion of the business district is at but a slight elevation above the river and is generally level. There are four hills surrounding the downtown section: Clover Hill on the north, Prospect Hill on the east, Phillips Hill on the south, and Tower Hill on the west.

Growth.

The population of the city has had a healthy growth. Figures from 1880 to 1924, inclusive, are shown in Table 1, and also data on water services and use of water.

TABLE 1.

POPULATION AND USE OF WATER IN LAWRENCE, MASS., 1880 TO 1924, INCLUSIVE.

Year.	Population.	Per cent. of Taps Metered.	Average Daily Pumpage M.G.D.	Gallons per Capita per Day.
1880	39 151	8	1.9	48
1885	38 862	16	2.3	59
1890	44 654	29	2.8	62
1895	52 164	56	2.8	54
1900	62 559	77	3.3	53
1905	70 050	88	3.0	43
1910	85 892	91	3.8	44
1915	90 259	93	4.0	44
1920	94 270	96	4.8	51
1925	95 136	98	....	..

* President and Chief Engineer, Morris Knowles, Inc., Consulting Engineers, Pittsburgh and Cleveland.
† Division Engineer, Morris Knowles, Inc.
‡ Superintendent, Water Department, Lawrence, Mass.

It is to be noted that the population figure for 1900 is about 10 000 less than was expected when the study of the growth of the city was made in 1871.

References.

In order to avoid repetition while preserving the record of these works, and to enable the reader to make the connection, attention is called to the fact that this paper is really an extension of two other papers which have been written about this subject. One appeared in the Transactions of the American Society of Civil Engineers for December, 1901, Vol. xlvi; being a paper by Messrs. Knowles and Hyde on "The Lawrence, Mass., City Filter." Another appeared in the Proceedings of this Association, in the JOURNAL for February, 1908; being a paper by Messrs. Knowles, Collins, and Marble on "Filter Operations: Investigations for Additional Supply and Construction of New Filter at Lawrence, Mass."

In each of these papers, reference has been made to general water supply conditions, with the presentation of the current statistics as to volume of supply and costs. Some of these tables have been extended and appear again. Others, particularly those giving filter operating and financial data, do not seem, because of peculiar local conditions, to be worthy of extension, and they therefore have been omitted.

History.

As a background of interest, the senior writer has always had more or less connection with the Lawrence Water Works and its development, some of which is an inherited interest arising out of the period of original construction when his paternal grandfather was one of the original Water Works Commissioners. This writer was a member of the Board of Water Commissioners from 1895 to 1900, during which time the high-service system was installed. He has made numerous investigations and reports, one being a comprehensive study of the entire situation. This was presented in December, 1917, and covered the question of securing an entirely new supply. Another, dwelling upon the recent conditions in the light of the delay in securing a new and adequate supply, was made in November, 1924. This latter resulted in the decision to build the additional filter and install the new pumps, which is now being carried out, and which is the direct cause of writing this paper. It will have largely to do with the studies and changes resulting from difficulties with the original supply, as a consequence of its character and the changing public opinion in regard thereto.

ORIGINAL WORKS.

General.

The Lawrence water system is about 50 years old and dates from a time when the city had a population of only 35 000. The original works were completed late in 1875, following a period of construction of about two

years. This, in turn, had been preceded by an investigation of the subject, resulting in a report of a Special Committee in December, 1871.

Supply Studies.

Several supplies were considered, viz.: the ponds in the vicinity, wells, and the Merrimac River. The latter was finally agreed upon as meeting the conditions of sufficient quantity, satisfactory quality, and minimum expense. It is interesting to read the report of the Special Committee, which dwells to a considerable extent upon this question of the satisfactory condition of the Merrimac River, the authors even going so far as to say that waters impregnated with sewage might afterwards become perfectly safe for use.

Description.

However, because of the desire to secure, as it was thought, some ground water and to eliminate occasional muddiness of the stream, it was decided to build a large infiltration gallery along the bank of the river. This was built of stone and brick 8 ft. high and 8 ft. wide, of horseshoe section, and extended 300 ft. easterly from the pumping station. Almost immediately, due to the silting with mud, this gallery became clogged and its further use impracticable. It was therefore abandoned about 1883, and water obtained directly from the river itself. It was later put into use again when the filter system was built, performing the function of the gathering conduit for the water from the underdrains of the filter.

The Leavitt double-unit pump had a capacity of 10 million gal. per day, or 5 million on each side, which could be used separately. This was one of the first installations of its kind, — a massive affair, and is still in use. The force main to the reservoir, together with the large distribution pipe for some distance toward the center of the city, was 30 in. in size. There was and is a separate main from the pumping station, 20 in. in size, down Water Street to the business district. The distribution reservoir has a capacity of about 40 million gal. and still remains one of the large installations for this purpose among the cities of moderate size in the country. It still gives a week's safe storage above the city and is closely attached to the pipe distribution system.

A sketch map of the city, showing the location of the principal physical features, thoroughfares, pumping station, reservoir, and principal mains is shown upon Fig. 1. This also presents the boundaries of the high-service districts, upon the four hills previously mentioned.

In their size and ample capacity, the first works reflect the far-seeing vision of the men who had to do with their development at that time, when it is likely that there was much criticism from the people of a small city as to the wisdom of such expense. We can appreciate that, with respect to its day and generation, the system was built with a view into the future. The amount of money spent for the original works, $1 200 000, is interesting

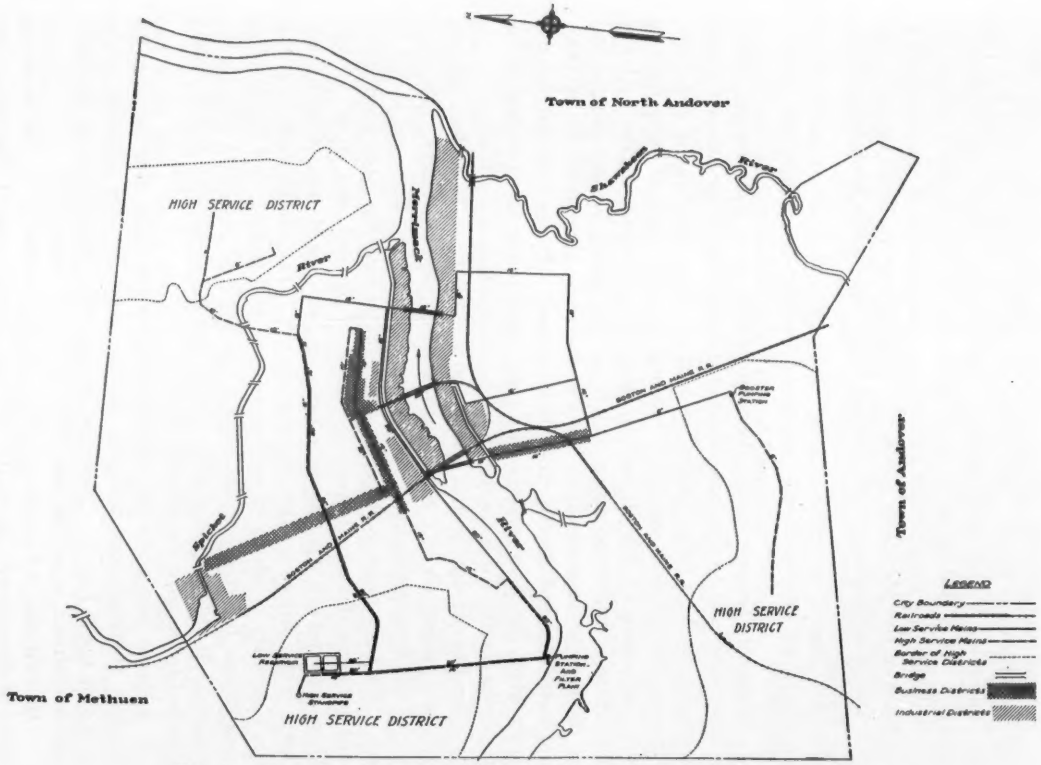


FIG. 1. — PRINCIPAL FEATURES OF WATER-WORKS SYSTEM OF LAWRENCE, MASS.

information, when one compares this with the niggardly expenditures which have been made in recent years to provide for this great public need.

Criticisms.

One of the writers remembers with much interest several discussions about these early provisions and their capacity, with his grandfather, who was one of the three Construction Commissioners. The stories about why such large units were built in order to provide for the future, and the antagonistic discussion which was caused thereby because of the feeling, on the part of some, that an undue amount of money was being spent, savors much of present-day events. In fact, in March, 1875, a report was made to the City Council by the Special Committee on this subject of extravagance in building. In this connection the following quotation from this report is of interest:

"We have considered, during the progress of the review, all facts brought to our notice, which seemed to demand, and were within the scope of our investigation, deeming it our duty to taxpayers so to do. We have not considered it our duty to scent vague rumor and nurse idle scandals, but rather, in the absence of direct charges, to confine our examination to the important question of the sufficiency and adaptation of the works to present or prospective needs, and to satisfy ourselves of the honest purpose of the Commissioners.

"We have endeavored to treat the Commissioners as men whose reputation, honorable record, and personal pride were in some measure involved in our action and entitled to just consideration; and have not considered ourselves as attorneys bound to make out a case against men engaged in responsible labor, by ignoring and belittling positive merit and magnifying trivial errors, but, as bound to decide without prejudice, and deal justly with public servants.

"In the failure of evidence to the contrary, and the tendency of facts presented in their favor, the Commissioners deserve, in our opinion, to stand as citizens of probity and good intent. We do not deem it our duty to lavish praise of those features of the works which have marked any peculiar excellence, for the reason that they are fully considered and endorsed by the Engineer in his report, and use of the works will evidently be the lasting defense of the builders against careless criticism or false statement. We condemn as unmanly and unjust that spirit of opposition which cannot content itself with free and proper criticism of what appear to be errors in judgment, but would trifle with reputation and shadow the good name of others to satisfy personal bias without substantiating by ample proof their assertions."

History repeats itself, and those who have occasion to carry out large public works are frequently the target for unjust criticism. The same is as true today as it was 50 years ago, and the breadth of view taken by these early investigators and the careful, judicious language used by them is worthy of emulation by those today interested in similar activities.

However, the results justify the decisions then made, for it has been remarkable, with a development of population of three times the number

then existing, that the Lawrence water works have, in the main, functioned to give satisfactory service. The only drawback has been that of quality, and this has been a progressive deterioration and one to be expected with the growing settlement of the country.

The fact that not all was anticipated at the time is not surprising in the then present state of knowledge. We must remember that nothing was known about bacteriology or the pathogenic theory of disease and that the methods of chemistry were the only methods of making an analysis to determine the constituents of water; and that, from this point of view, as expressed by all authorities at that time, the Merrimac River was a satisfactory source of supply.

Periods of Development.

Six Stages.

The periods of development of the Lawrence water works may be stated as six in number.

The first was the series of studies from 1871 to 1874, which was the outgrowth of the popular desire for the installation of a municipal water supply. This resulted in the supply being put in service in 1876.

The second was a series of investigations, during the period from 1887 to 1893, which was the era of the birth of the sciences of bacteriology and pathogeny. Much of the work of study and progress was by the Massachusetts State Board of Health and resulted from the installation of the Lawrence Experiment Station. These culminated in 1892 in the building of the slow sand filter; the first one, as stated by its designer, the late Hiram F. Mills, C.E., built with the definite theory of preventing diseases in the human family. The filter was placed in operation in September, 1893.

The third period covered a series of investigations resulting from the growth of the city and the demand for increased service. This brought about the installation of the high-service system in the year 1895. Since that time it has been somewhat extended, particularly for the purpose of fire protection in the business section. A separate high-service area, with booster pump, has recently been installed in the Phillips Hill district in South Lawrence, west of South Broadway.

The fourth began in 1905 and had its inception in the imperative necessity for increased quantity of water, and in some dissatisfaction with the river supply. Extensive well tests and other investigations were made, but finally, in 1907, there resulted the building of a three-quarter acre filter west of the units first built.

The fifth period covered 1915 to 1917. There had been a growing realization of the inadequacy of the works of supply, and of popular antipathy to the quality of the water, which may be summed up as a state of general public dissatisfaction. This resulted in a comprehensive study of all of the possible sources of supply, within a reasonable distance of

Lawrence. Report was made to a specially appointed Water Commission created for the purpose of considering the whole subject. Procrastination, other than with this Commission, however, and delays of various kinds, have resulted in no accomplishment. The Water Commission still exists, in coördination with the Methuen Water Board and the State Department of Health, to consider a comprehensive new supply.

The sixth period began in 1924, as a result of a realization that something must be done, even if a new supply could be obtained within a reasonable time. This resulted in the report of November, 1924, with the recommendation that, pending the securing of a new supply, a new slow sand filter be built to augment the present amount of water to be obtained from the Merrimac River. At the same time the recommendations with regard to pumping units, as first made with regard to the Leavitt pumps in 1911, were repeated, stating that a new or augmented installation should be made.

Change in Quality.

With the passing of years, it became evident that the sanguine early beliefs with regard to satisfactory condition of the Merrimac River were not being borne out. It was not until the development of the science of bacteriology and the epic studies of the Massachusetts State Board of Health, however, that the importance of a water supply with regard to public health was fully realized. The best evidence of this changed condition, which also reflects the beneficial result coming from a pure water supply, is shown in Table 2, which gives the typhoid fever mortality record for Lawrence for the past ten years, compared with that for the State of Massachusetts and with the average of various selected periods for Lawrence.

Of course the seriousness of the situation at Lawrence was made noticeable to a large extent by the fact that typhoid fever epidemics in Lowell were followed by prevalence of the same disease in Lawrence. When we realize the state of the art at the time and the difficulty of convincing the taxpayers of the results to be obtained, we appreciate what a remarkable performance it was for Mr. Mills to have secured the approval of the authorities to build this original filter of two and one-half acres in size. Its cost was remarkably low, only about $65 000, which, together with additions up to the year 1900, made a total cost of only about $80 000.

Increased Need.

Up to 1893 not much attention had been paid to curtailing water waste in Lawrence, but at that time a campaign of metering was started. That this was successful in keeping the quantity of water down is evidenced by the statistics in Table 1. About this time of reducing waste, or by 1899, the filter showed evidence of clogging. We now realize that some of this was to have been expected with uncovered filters and ice troubles in winter, with lack of tight bottom and consequent algae troubles from ground water,

TABLE 2.

REPORTED CASES OF TYPHOID FEVER AND DEATHS RESULTING THEREFROM IN LAWRENCE, MASS., FOR THE TEN YEARS 1915–1924; COMPARED WITH AVERAGE OF VARIOUS SELECTED PERIODS.

Year.	Number of Cases.		Number of Deaths.		Per cent. of Cases Resulting in Death.	Typhoid Fever Death Rate Per 10 000. State of Massachusetts.
	Total Reported.	Per 10 000 Population.	Total Reported.	Per 10 000 Population.		
1915	62	6.9	7	0.78	11	0.66
1916	69	7.6	7	0.77	10	0.46
1917	35	3.8	6	0.65	17	0.46
1918	38	4.1	9	0.97	24	0.41
1919	77	8.2	7	0.75	9	0.26
1920	52	5.5	6	0.64	11	0.25
1921	21	2.2	4	0.42	19	0.31
1922	18	1.9	1	0.11	6	0.22
1923	38	4.0	4	0.42	11	0.18
1924	17	1.8	3	0.32	18	....
Average	43	4.6	5	0.58	13	0.36*
Average 6 yrs. (1887–92) prior to introduction of filtered water	188	43	53	12.0	28	4.0
Average 6 yrs. (1894–99) subsequent to introduction of filtered water	84	15	14	2.6	18	2.6
Average 7 yrs. (1901–1907)	106	15	15	2.0	14	1.7
Per cent. Reduction:						
1915–24 below 1887–92	77%	90%	91%	95%	54%	91%
1915–24 below 1894–99	49%	70%	64%	78%	28%	86%
1915–24 below 1901–07	59%	70%	67%	71%	7%	79%

* 9 years average.

and difficulty with old river silt and mud. But it is undoubtedly true that lack of appreciation of the processes of filtration, and resultant careless operating conditions, increased this tendency to a considerable extent. It became so bad that some attempts at relief were made in 1898 and 1900 by cleaning the clogged underdrains and renewing gravel and sand. Additional need of new filters developed in 1902. Dividing walls in the open filters gave some relief in winter, as one unit could be closed for cleaning while operating two-thirds of the area. This improvement and benefit is to be attributed to the late M. F. Collins, former superintendent, and member of this Association.

New Supply Considered.

Conditions, however, became seriously worse and in 1904 and 1905 the city was faced with water famine. There was only a two days' supply in the reservoir on March 14, 1905. This was the occasion of the first attempts to purchase water from neighboring towns, but this was without avail at that time. Because of the delay, the legislature of 1905 passed an act, permitting the city of Lawrence to draw water from the towns of Andover, North Andover, and Methuen; from all or any one of them, at times of need. This has been practiced from that date until the present time as needful occasion has arisen.

Some consideration also was given as to whether water could be obtained from upland sources, and some well tests and investigations were made. About 100 test wells were sunk for this purpose, eight months' time and some $6 000 being expended. It is interesting to note that one of the fields investigated and declared unfit, on account of carbonic acid in the water, was later approved for the adjoining town of Methuen and utilized. In the latter case, however, lead service pipes were not in use as in Lawrence wherein such a supply would be somewhat dangerous.

Use of water from the Metropolitan Water Supply was also discussed at this time. In 1906 the construction of a new three-quarter acre covered filter was authorized and this was completed in 1907. Money for this was first requested in 1903. When the work was carried on it was not without some vicissitudes and delays, one being the failure of the roof. All of this is described in the paper read before this Association on February 12, 1908.

In this connection it must be remembered that the original filter did not have a tight bottom (thereby gaining economy in construction). As a result some of the ground water and muck from the original excavation entered the underdrains and produced clogging. It is also true that much of the unpleasant condition of the Lawrence water supply, popularly attributed to the sewage-laden stream, containing wastes from Lowell and other cities above, was in reality caused by organisms present in the ground water which entered the underdrains. These produced not only disagreeable tastes and odors but stains upon clothes.

As a result of continued and expressed dissatisfaction and an order from the State Board of Health, the Water Department in 1916 did reconstruct the easterly third of the old filter, put in a tight bottom and built walls and piers. Then during the next year a groined arched roof was added.

Investigations of 1915–1917.

It is now the purpose of this paper to recapitulate in a concise statement the events and studies of the last ten years, and to then explain the present situation and the work contemplated, in order to eke out the present supply system until something of a permanent nature can be accomplished.

Unpleasant River Water.

This deep-seated dissatisfaction, even violent resentment, against the Merrimac River as a source of water supply, finally found its expression in June, 1915, in the appointment of a Special Water Commission, to investigate the possibilities of new sources of supply. This resulted in a thoroughgoing study of the entire situation, including prognostications as to the future and recommendations as to a new source of supply.

It was concluded that notwithstanding the theoretical safety there was not only popular disapproval and misapprehension, but that there were actual lapses in efficiency, such that the death rate from typhoid fever at Lawrence has not in recent years been all that should be expected with an absolutely safe water supply, or up to modern urban standards. It is possible to produce new and better conditions with an adequate filtration system, provided with up-to-date, tight, covered filters, avoiding ground water and difficulties from winter conditions. At the same time sufficient sedimentation, and pre-treatment to avoid overloading the sand filters themselves, will materially make the results more certain.

Various surface supplies were studied, including some twenty different projects. Some of these included filtration of the river water under various schemes and with the supply obtained from various points upstream. Some of the projects included wells and some impounded supplies, a few of these being within the state of New Hampshire. Because of the fact that this report has never been published, it may be worth while to dwell upon some of the salient features and explain why certain conclusions were reached, which to the authors seem sound at the present time.

Need of New Supply.

For some time it has been difficult to secure sufficient water from the filters at Lawrence to supply the needs of the city at times of great stress. This has occurred particularly in the winter time, partly because of increased use, but largely because of decreased yield. The latter arises somewhat from increased viscosity of the water, but mostly from clogged conditions in the filter beds.

That this is an important factor is apparent from the record of the amounts of water purchased in the various years since 1916, reaching as high as an average of one-half million gal. per day. In 1917 when investigations were made, it was found that there was paid by the inhabitants of Lawrence for purchasing bottled spring water as much as $70 000 per year, or 55 per cent. of the average annual amount paid into the city treasury for use of the city water supply — truly a remarkable situation when one considers that, to a reasonable extent, the municipal water supply was safe.

Summary of Report.

Because of the previously stated objection to filtered Merrimac River water under the best of conditions, the conclusion of the 1915–1917 investigation was to secure a new supply, and this from a less contaminated source.

Some of the supplies from over the state border in New Hampshire were and are excellent and these, from the point of view of capacity and cost, proved very desirable. It was realized, however, that if dependence be placed upon the exercise of precautions to secure purity within an adjoining state, it would not be a wise procedure.

For that reason many supplies were eliminated which had this serious defect. There was one supply, however, which, while providing for extensions within the state of New Hampshire, would be good for a number of years with all of the works built within the state of Massachusetts. It was early determined that in such a new project provision should be made for some growth in the future. Therefore a population of 150 000 and a quantity of 7.5 million gal. per day, which was expected in 1940, was thought to be the desirable allowance for the new supply.

Of all of the supplies studied, the one which appeared most favorable is that from Bartlett's Brook, which runs into the Merrimac River at a point one and one-half miles above the westerly city limits. The stream has its headwaters in Pelham, N. H., and has a drainage area of about seven sq. miles at the proposed point of intake, about a quarter of a mile upstream from the mouth of the brook. A dam was proposed across the stream just above North Lowell Street, providing a reservoir of about 1 900 million gal. capacity. The watershed is sparsely populated, with most of the population near the lower limits of the basin and several summer camps near the upper end of the drainage areas.

It was proposed to clear and grub the reservoir site, drain swamps, and remove peat, but not to strip the basin. It is evident that continued filtration would be advisable, although not absolutely necessary, thereby avoiding stripping of the flooded area and providing for future development on the watershed; without continued filtration, storage in the reservoir would be sufficient not only to bleach the color of the water, but also to provide sufficient sedimentation and lack of proper food, so that bacteria would die and decrease in numbers. Water would flow by gravity from the reservoir to the present filter plant and pumping stations.

While the maximum possible development of this watershed alone is approximately 5 million gal. per day, or the amount needed for Lawrence at the present time, it is possible to augment this stream by the diversion of water from other drainage areas. These include Harris Pond, Island Pond in Pelham, N. H., and in the future diversion of the Spicket River. There are also possible sites for storage reservoirs on the Spicket River. These would necessitate the acquirement of water rights, and possible interstate complications.

The difficulties as to control of quality would not be serious, however, for while a portion of the supply would come from over the New Hampshire border line, the project would provide, as before stated, for filtration and this would be done at the present site in Massachusetts. At the time it was studied, the total cost of this project for Lawrence (including Bartlett's Brook and Harris Pond) was estimated to be $817 000. Using index figures the probable cost at the present time would be $1 300 000.

An alternate supply was considered on Salmon Brook west of Lowell, but this was found less favorable than the Bartlett's Brook supply.

Metropolitan Needs.

The need of additional water for the town of Methuen had become apparent, and therefore the requirements for both municipalities were considered in this study.

The Bartlett's Brook supply, as above described, was found the most favorable of those studied for a metropolitan supply. The 1940 quantity used in this case was 10.5 million gal. per day. The recommended plan contained some modifications and combinations of the projects studied, and proposed a supply adequate for both communities. The cost of the initial investment at the time it was studied was $900 000, including all pumping and purification works required. Conditions have changed materially since the previous figures were made, both as regards requirements and availability, and it is now estimated that the cost of the initial investment would be approximately $1 900 000. This, however, would be adequate for a somewhat longer period than the previous plan.

Views of the State Department of Health.

In the consideration of this report by the State Department of Health, the interstate difficulties loomed large, and the fact that the supply would not be good for a long time without augmentation from outside the state, caused unfavorable reaction and an adverse report in 1918. The situation is complicated by the fact that the city of Lowell and its environs also have had, from time to time, to pay attention to the adequacy of their water supply.

For that reason, as well as a growing scarcity of all of the supplies of the state, the Department of Health believes that the needs of Lowell and Dracut should be considered when studying the requirements of the Merri-

mac River valley. Therefore, the Department has been of the opinion that the source of supply on Salmon Brook, as discussed in its later report of March, 1923, is likely to be the most favorable, when taking into account the needs of all the communities in the Merrimac valley.

From time to time, also, consideration has been given to the bringing in of the Metropolitan Water Supply, either to come from Spot Pond, from the reservoir in Weston, or from the impounded supply itself of the Nashua River near Clinton. These supplies from all the different places are still under consideration and the city of Lawrence, through its Water Commission and that of Methuen, working with the State Department of Health, has been asked to say, upon further investigation, what should be the best source of supply, considering all of the factors.

This matter of interstate relationships of such water problems raises some interesting questions. These were discussed by the senior writer, in connection with the paper by Leonard P. Wood in the *Journal of the American Water Works Associatiou* for May, 1925. The situation is certainly unfortunate and well worthy of the attention of water supply authorities, engineers, and attorneys. It is important to determine what may be done instead of going long distances within the state lines to some unfavorable sites, when nearby there is frequently an abundant supply of great purity, which may be going to waste, but is simply beyond the state line. Then again, the obtaining of water from distant rural sources brings out all of the antagonism of the farming districts, the people of which feel that water should not be carried such long distance when means exist close at hand for securing adequate supplies.

Present Situation.

Delays Serious.

This report on the Lawrence and Methuen water supply situation was made in December, 1917, and a report of the Department of Health on this subject, above referred to, was issued about a year later, in December, 1918. Procrastination still continued and nothing was accomplished. It is true that in the meantime Methuen, having developed a serious situation with regard to quantity, did put in an auxiliary supply from wells, with electric-driven pumps, on the north shore of the Merrimac River in the vicinity of Pine Island. This was the source of supply which had previously been refused the city of Lawrence because the latter had so large a number of lead services in use.

But nothing was being accomplished for the city of Lawrence, nor was anything being done for comity of relationships. In fact the bill introduced into the legislature, in the session of 1922, for the purpose of giving the city of Lawrence rights upon Bartlett's Brook, was bitterly opposed by the town of Methuen. This was notwithstanding the fact that efforts were made, if such supply were secured and Methuen were willing to join, to promote an arrangement for such dual system in the planning of the works.

All of this brought about a serious situation for Lawrence, with grave apprehension as to whether it could successfully meet its needs to supply the people with sufficient good drinking water. It is true that water could be bought at times of dire need, but this was extremely expensive, much more than the annual charges on an equivalent quantity of water derived from a new and permanent supply. And no municipality of virile statesmanship likes to be dependent upon its neighbors, under such tenuous arrangements, for the water it needs at times of stress.

Investigational Activities.

In the meantime it was clear that not only did the city of Lawrence need a new water supply, but that the work done for Methuen was of a decidedly temporary character and would need to be augmented in a permanent fashion within the space of a few years. In addition to this, there was some evidence that the supply of the city of Lowell was not all that could be desired for a community of this size, looking a long time into the future. Its neighbor, the town of Dracut, also needed attention with regard to its supply.

This brought about a request on the part of the legislature, stimulated by local activity, to have an investigation made by the State Department of Public Health. This authorization was passed during the session of 1922, but was limited in its phraseology to the city of Lawrence and the town of Methuen. Studies were also limited to "Sites suitable for storage reservoirs in the watershed of the Merrimac River, within the limits of the Commonwealth." This report was made and presented to the legislature in March, 1923.

The conclusions arrived at therein are that Bartlett's Brook is not a suitable supply, for the reasons previously stated, and that Salmon Brook is a suitable source. It states, among other things, that one of the reasons for this is that such source may be utilized through combined efforts, for the city of Lowell and the town of Dracut, as well as the city of Lawrence and the town of Methuen. The report concludes that as the authority under the resolve does not permit the inclusion of other municipalities than those first authorized, and as the expense is so great for the two alone, the selection of this source at the present time is inadvisable under the circumstances, notwithstanding its good quality and the abundance of the supply.

For this reason the report recommends that a study of the whole water supply question of the Merrimac River valley be made. This was also previously recommended. It also included a statement that such investigations should be made without delay, because it was apparent that the recent years of abundant rain were likely to be followed by years of deficiency. Lawrence was advised in the meantime that it should either purchase water from neighboring towns or enlarge its filtration works; Methuen was told that it must depend upon its wells near the Spicket River, together with

the augmented supply from Pine Island wells and, if no serious delay resulted, this probably would be sufficient until a new supply could be obtained.

Other Municipal Activities.

In view of this long delay and continued procrastination, it is worth while for those charged with such responsibilities in the several cities and towns, to analyze the situation and draw some conclusions from these experiences. While apathy may be in some measure responsible, this situation probably results mainly from lack of understanding, or perhaps even from inability to direct concentration of public interest in a definite direction. For while there have always been various needs, sometimes only to raise money for popular endeavors, there has never been a time when the money has not been forthcoming for new capital expenditures. In some years this has been either in excess of or equal to the amount of money that would be required for a new water supply.

It is of interest to note, in Table 3, the amounts of money that have been appropriated in Lawrence in the years since 1915, for various public works and improvements. There is no question that all of these are proper, laudable, and worth while; but there is serious doubt whether many of them are of such transcendent importance as that of a safe public water supply. Note that out of the munificent sum of $5 849 000 spent in ten years, only $135 000, or barely 2⅓ per cent., was expended on the public water supply.

The answer must be found in some other way. It may perhaps be summed up in the statement of the lack of selling ability of the subject of water supply, compared with such popular improvements as pavements, parks, playgrounds, bridges, and other pressing needs like schools and sewers. In the first place, the water-works system does not have an appealing call because its need is not realized until there be an epidemic arising from poor quality, or a serious conflagration brought about by insufficient quantity or lack of pressure.

It takes a startling catastrophe to make the public realize its complete dependence upon an adequate water supply, although it is the one thing without which they cannot exist. We may live without schools, although we would be poor citizens; we may live without paved streets and bridges, although with great inconvenience; we may continue to live without attractive parks and playgrounds, although we might become an hectic people and our youth have less chance for wise development. We may even get along without a water carrier system for sewers, as is done in some army camps, although with considerable nuisance and with some danger to the public health; but we shall positively die within a short time if we fail to have drinking water.

Why is it this cannot be realized? Why is it that the city fathers, with their ears to the ground as they should be, do not hear the call for this transcendent requirement? The situation may be attributed to two facts,

TABLE 3.

SUMMARY OF BOND ISSUES FOR CAPITAL EXPENDITURES, EXCLUDING WAR AND EMERGENCY ISSUES, CITY OF LAWRENCE, MASS., 1915–1924 INCLUSIVE.

	1915	1916	1917	1918	1919	1920	1921	1922	1923	1924	Total.
Sewer	$100 000	$27 000	$15 000	.....	$40 000	.....	.....	$50 000	$295 000	.....	$527 000
Sidewalk	.....	.....	30 000	.....	.....	.....	$25 000	25 000	25 000	.....	105 000
Paving	.....	50 000	.....	.....	175 000	$150 000	215 000	150 000	180 000	$160 000	1 080 000
School	140 000	150 000	75 000	$30 000	.....	.....	600 000	420 000	670 000	.....	2 085 000
Bridge	600 000	.....	165 000	120 000	40 000	.....	.....	.....	.....	.....	925 000
Playground	.....	5 200	40 000	.....	.....	40 000	.....	.....	.....	.....	85 200
Boulevard	.....	45 000	.....	.....	.....	.....	.....	.....	.....	.....	45 000
Water and Filter	.....	60 000	.....	60 000	.....	.....	.....	15 000	.....	.....	135 000
Municipal Garage	.....	.....	.....	.....	.....	.....	40 000	.....	.....	.....	40 000
Fire Apparatus	.....	.....	.....	.....	.....	.....	80 000	.....	.....	.....	80 000
Bath House	.....	.....	.....	.....	.....	.....	.....	40 000	.....	.....	40 000
Municipal Building	.....	.....	.....	.....	.....	.....	.....	.....	300 000	300 000	600 000
T. B. Hospital	.....	.....	.....	.....	.....	.....	.....	.....	.....	192 000	192 000
Total for Year	$840 000	$337 200	$325 000	$210 000	$255 000	$190 000	$960 000	$700 000	$1 470 000	$652 000	$5 849 200

— *first*, lack of public observation, and *second*, lack of appeal to the voting class. Your City Commissioner is constantly importuned to build some public improvement in a certain ward or in a neighborhood — to build a bridge here, or pave a street there — and when it is done the work is visible and everybody realizes its benefit and its magnitude. The same thing is true of the schoolhouse or playgrounds.

Again, on many of such works, local voters are employed on the construction program and this, too, has its appeal to the practical politician. Now all of this should be realized and discounted, and the man who is interested in the water-works problem, because he knows the need and lives in the community, has a grave and important duty to see that he is untiring in acquainting people with the facts and in preventing their being lulled into a false sense of security because they do not realize the situation.

Situation Acute.

Here is a story of public moneys being spent in many ways, but there is lack of a combined, coördinated force of civic spirit, sufficient to present a forceful attitude to the municipal and state legislatures, so that the needs of the municipalities on this important subject will be cared for. This delay has brought Lawrence to the situation where it is continuing to use old-type filters, with excessively expensive methods of maintenance; pumps which are inefficient in duty and likely to collapse because of worn condition; and where it is altogether depending upon a series of weakened reeds — all because it is afraid to spend money, not knowing how soon it would have to scrap a great deal of it if a new supply were to be built.

The situation has gone so far, however, that no further delay should be permitted. Those in responsible and direct charge of the water supply were not satisfied to face unusual and unanticipated annual expenditures for buying water, and even dangers of water famine. They decided that something must be done even though built in the nature of temporary works. This brought about the desire for the emergency study in 1924.

Present Emergency Construction.

1924 Report.

A realization of this situation by the Director of Engineering, Hon. Patrick F. McNulty, and the Superintendent of Water Works, Patrick S. Nugent, developed into a resolve to do something to make it safe for the city of Lawrence to depend upon its present system of supply until a new one could be secured. This was stimulated by a review of the situation, for the Lawrence Chamber of Commerce, by Chester H. Wells, C.E., who, in August, 1924, presented a report and recommended immediate construction of additional filter capacity.

It will be worth while to recapitulate the situation as it was found. The filtration facilities consisted of 3.2 acres of slow sand filters in four different units, about one-half of which is covered and one-half open.

The dependence for low-service supply was upon two 5 million gal.

Leavitt pumps, installed in 1876; an inefficient direct-acting pump of 1 million gal. capacity; and a centrifugal pump, installed in 1912, of 3 million gal. capacity. The dependence for high-service supply was upon a vertical crank and fly-wheel pump, manufactured by the Barr Pumping Engine Company, and installed in 1896. This is of 1½ million gal. capacity. The low-service, direct-acting and centrifugal pump already mentioned could also be used for high-service pumping. Boilers, two in number, were installed in 1900, at a total rated capacity of 280 h.p.

Water was still being bought from neighboring towns, sometimes as much as one-half million gal. a day. The filters, somewhat inadequate and clogged, would undoubtedly yield more water if they were thoroughly overhauled, the underdrains cleaned, and if they had a tight floor to eliminate ground water. It was concluded in the report that a safe capacity of the filters was 5½ million gal. per day. The normal use of water was 4 million gal. per day for low service and about 1 million gal. per day for high service, with the latter increasing rapidly. It is estimated for 1935 that the low-service requirements will be 5 million gal. per day and high service 1½ million gal. per day.

Various projects were studied, including the use of pre-filters, in order to pass water more rapidly through the final filters; covering the present open filters, after overhauling and putting in a floor system, to keep out ground water; and location of a new covered filter, both three-quarters of an acre and one acre in area, and at three different sites. One was west of the boiler house, the second was north of the pumping station on Water Street, and the third between Water Street and the location of the present open filters. At the same time studies were made with regard to additional pumping and boiler capacity.

The conclusions and recommendations in the report were to build a three-quarter acre covered filter, just north of the present open filters. Then the easterly unit of the uncovered filter is to be reconstructed and made tight, and covered. The next step is to reconstruct the westerly half. It was recommended also that a pump be installed which would be of a capacity to lift water from the well to the low-service reservoir and at the same time also be capable of taking water out of the Water Street main and lifting it to the high-service standpipe. This would also require a new boiler, of 140 h.p., together with its auxiliaries.

There are times when the water in the Merrimac River is too low to flow into the surface of the filter by gravity, and for this reason it was recommended that a pump of 6½ million gal. be installed for this purpose. It was estimated that the total cost of this improvement would be $450 000. The general arrangement is shown on Fig. 2.

Work Authorized.

The above report was made in November, 1924. Shortly after the first of the year, in January, 1925, the subject was considered by the City

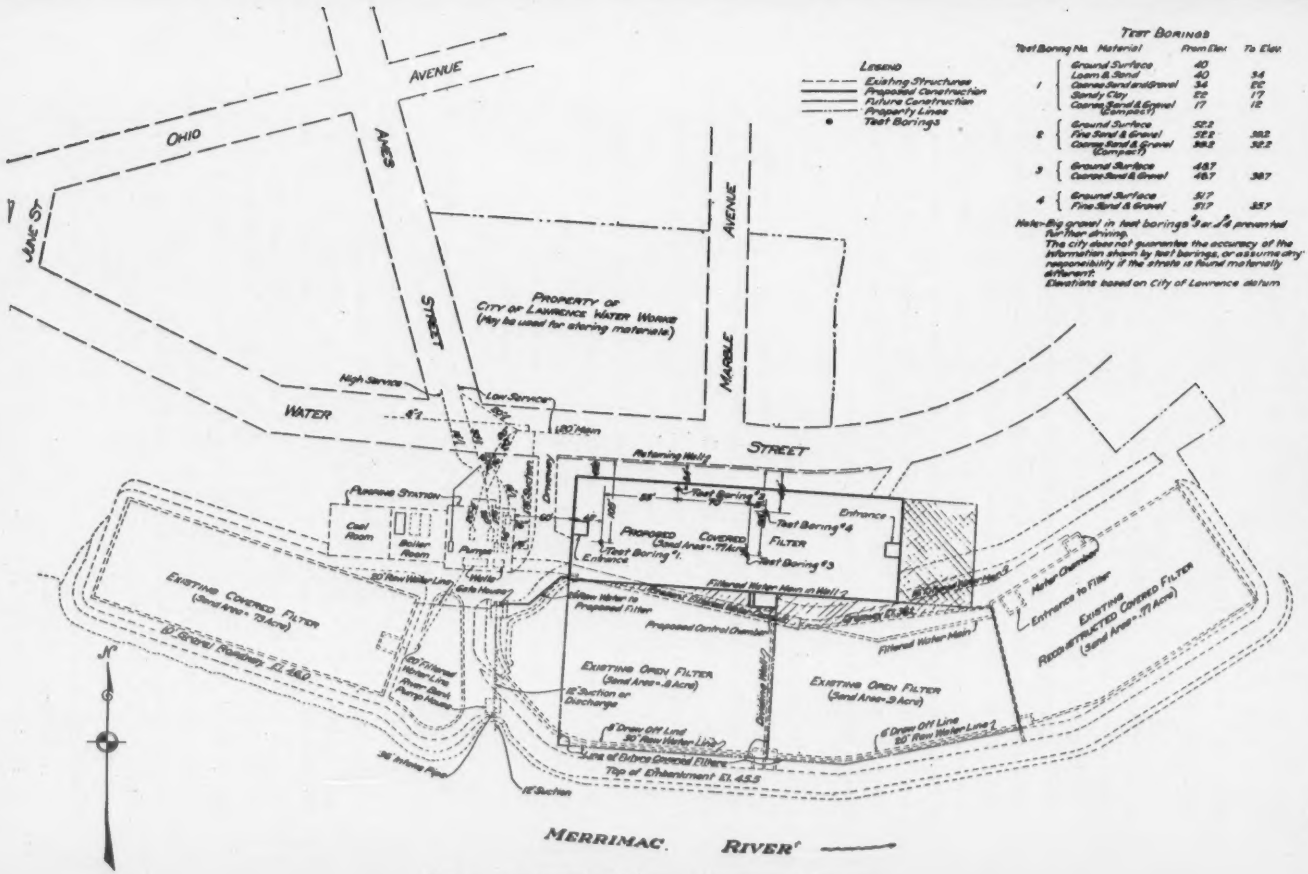

AVENUE
OHIO
JANE ST.
AMES
STREET
MARBLE
AVENUE
STREET
WATER
PROPERTY OF CITY OF LAWRENCE WATER WORKS (May be used for storing materials)
High Service
Low Service
180' Main
Pumping Station
Coal Room
Boiler Room
Pumps
Valves
Gate House
Returning Waste
Test Boring #2
Test Boring #1
Test Boring #3
Test Boring #4
Entrance
PROPOSED COVERED FILTER (Sand Area = 1.7 Acre)
EXISTING COVERED FILTER (Sand Area = 1.3 Acre)
20" Raw Water Line
Filtered Water Main on Wall 2
Filtered Water Main
Influent Water to Proposed Filter
Proposed Control Chamber
Existing Wall
Water Chamber
Entrance to Filter
EXISTING RECONSTRUCTED COVERED FILTER (Sand Area = 1.7 Acre)
EXISTING OPEN FILTER (Sand Area = .8 Acre)
EXISTING OPEN FILTER (Sand Area = .3 Acre)
12" Suction or Discharge
6" Drain Off Line
20" Raw Water Line
Line of Extra Covered Filters
Top of Embankment El. 45.5
16" Suction
36" Intake Pipe
20" Raw Water Line
Pump House
Pump Room
20" Filtered Water Line
Concrete Roadway El. 34.0
N
MERRIMAC RIVER
LEGEND
Existing Structures
Proposed Construction
Future Construction
Property Lines
Test Borings
TEST BORINGS
Test Boring No. | Material | From Elev. | To Elev.
1 | Ground Surface | 40 |
Loam & Sand | 40 | 34
Coarse Sand and Gravel | 34 | 22
Sandy Clay | 22 | 17
Coarse Sand & Gravel (Compact) | 17 | 12
2 | Ground Surface | 52.2 |
Fine Sand & Gravel | 52.2 | 38.2
Coarse Sand & Gravel (Compact) | 38.2 | 32.2
3 | Ground Surface | 46.7 |
Coarse Sand & Gravel | 46.7 | 38.7
4 | Ground Surface | 51.7 |
Fine Sand & Gravel | 51.7 | 35.7
Note—Big gravel in test borings 3 & 4 prevented further driving.
The city does not guarantee the accuracy of the information shown by test borings, or assume any responsibility if the strata is found materially different.
Elevations based on City of Lawrence datum

FIG. 2. — LAWRENCE, MASS. ADDITIONAL FILTER.

Council and it was decided to authorize the preparation of designs and receive bids for the additional covered filter and the pumps and boiler. This work was undertaken and plans were completed so that bids on the filter were received June 1, 1925.

In the meantime tests upon the amount of water obtained from the present filters indicated that the present westerly filter was not yielding what was to be expected. It was apparent that it was giving much less.

For this reason bids were taken upon both three-quarter and one acre filters, and when received the engineers and Superintendent of Water Works made recommendations that the full acre filter be built. This was in order that there should be ample security until other changes should be made or a new supply be secured. It will be remembered in this connection that, notwithstanding the complete recommendations, the authority was given only for one additional unit of new filter. Implications were presented, however, and assurance given, that the remodeling of uncovered filters would take place immediately thereafter.

Type of Filter.

The form of filter now under construction is of the usual slow sand type, all of concrete construction with reinforced side walls and inverted groined arch floor. The roof, however, is of flat slab construction instead of being of groined arches. It is believed that for so small an area slab construction is somewhat cheaper than the arch.

The method of underdrainage and amounts of gravel and sand are the customary ones. There are no unusual or unique factors in the construction, unless it be the provisions for heating and draining the filter. Some difficulty has been experienced at Lawrence with freezing of the water and sand when cleaning in winter, even with covered filters. It has therefore been planned to run a steam pipe to a chamber just inside the doorway near the pumping station. A fan is to be installed here to circulate heated air through the filter in times of extreme cold weather.

It was also thought desirable to provide an electric pumping unit in the control chamber, so that the filter may be quickly drained to get at it for scraping when it has been shut down. This pump will connect with the underdrainage system and will also supply water over the surface of the sand, as well as pump water, lifting it over the bank into the river.

In order to provide for future contingencies and regulation of the other four units of filters in the vicinity, a gate chamber has been built of larger proportions than necessary for this filter alone. Four Venturi tubes have been placed and provision made, so that the effluent water from each of the filters will run into this gate chamber, for regulation and measurement purposes. In fact, even before the open units are covered, it is planned to connect up the underdrains and laterals to the conduit pipe running into this regulating chamber.

No discussion has been had with regard to the kind of filtration pro-

Item.	Description.	Unit.	Approximate Quantities.	Engineer's Estimate.		Patrick J. H 24 Ames St., L	
				Unit Price.	Amount.	Unit Price.	
1	Excavation and disposal	cu. yd.	31 500	$1.00	$31 500.00	$1.00	$3
1 A*	Excavation and disposal	cu. yd.	7 000	1.00	7 000.00	1.00	
1 B†	Excavation and disposal	cu. yd.	2 100	1.00	2 100.00	1.00	
2	By-pass for filtered water conduit	lump	.....	2 000.00	2 000.00	2 000.00	
3	Rock slope paving	sq. yd.	900	4.00	3 600.00	2.00	
3 A	Rock slope paving	sq. yd.	200	4.00	800.00	2.00	
4	Concrete masonry (floors and footings)	cu. yd.	1 375	18.00	24 750.00	20.00	27
4 A	Concrete masonry (floors and footings)	cu. yd.	250	18.00	4 500.00	20.00	
5	Concrete masonry (walls)	cu. yd.	950	22.00	20 900.00	20.00	19
5 A	Concrete masonry (walls)	cu. yd.	175	22.00	3 850.00	20.00	
6	Concrete masonry (piers)	cu. yd.	175	30.00	5 250.00	20.00	
6 A	Concrete masonry (piers)	cu. yd.	40	30.00	1 200.00	20.00	
7	Concrete masonry (roof)	cu. yd.	1 075	25.00	26 875.00	20.00	21
7 A	Concrete masonry (roof)	cu. yd.	250	25.00	6 250.00	20.00	
8	Steel reinforcement	pound	370 000	.05	18 500.00	.04	14
8 A	Steel reinforcement	pound	68 000	.05	3 400.00	.04	2
9	Cast-iron pipe (bell and spigot)	ton	36	90.00	3 240.00	100.00	3
10	Cast-iron specials (bell and spigot)	ton	15	180.00	2 700.00	200.00	3
11	Cast-iron specials (flanged)	ton	7	240.00	1 680.00	250.00	1
12	20-in. Inlet regulating valve and chamber	each	1	500.00	500.00	400.00	
13	Controller, rate of flow and loss of head gage	each	1	1 600.00	1 600.00	500.00	
13 A	Controller, rate of flow and loss of head gage	each	1	1 800.00	1 800.00	600.00	
13 B1	14-in. Controller, rate of flow and loss of head gage	each	1	1 600.00	1 600.00	500.00	
13 B2	16-in. Controllers, rate of flow and loss of head gages	each	2	1 800.00	3 600.00	600.00	1
14	20-in. Hub and gate valves (stem nut and valve box)	each	3	200.00	600.00	200.00	
15	16-in. Gate valves (flanged end extension stem and valve stand)	each	4	170.00	680.00	175.00	
16	14-in. Gate valves (flanged end, extension stem and valve stand)	each	4	140.00	560.00	150.00	
17	12-in. Gate valves (hub end stem nut and valve box)	each	2	110.00	220.00	125.00	
18	10-in. Gate valves (flanged end extension stem and valve stand)	each	4	90.00	360.00	100.00	
19	10-in. Gate valves (flanged end and hand wheel)	each	4	90.00	360.00	85.00	
20	8-in. Gate valve (flanged end extension stem and valve stand)	each	1	70.00	70.00	75.00	
21	8-in. Gate valve (hub end stem nut and valve box)	each	1	70.00	70.00	75.00	
22	4-in. Gate valve (flanged end extension stem and valve stand)	each	1	50.00	50.00	60.00	
23	2½-in. Hose valves (hand wheel and threaded to fit city of Lawrence fire hose)	each	6	20.00	120.00	625.00	3
24	12-in. Half round tile underdrains	foot	1 950	.80	1 560.00	.50	
24 A	12-in. Half round tile underdrains	foot	450	.80	360.00	.50	
25	8-in. Half round tile underdrains	foot	90	.70	63.00	.40	
26	Filter gravel	cu. yd.	800	3.00	2 400.00	3.50	2
26 A	Filter gravel	cu. yd.	180	3.00	540.00	3.50	
27	Filter sand	cu. yd.	5 000	2.25	11 250.00	3.00	15
27 A	Filter sand	cu. yd.	1 200	2.25	2 700.00	3.00	3
28	Miscellaneous cast-iron wrought iron and steel	pound	15 000	.10	1 500.00	.20	3
28 A	Miscellaneous cast-iron, wrought iron and steel	pound	3 500	.10	350.00	.20	
29	Superstructure, control chamber	lump	.....	1 500.00	1 500.00	2 000.00	2
30	Heating and ventilating system	lump	.....	3 000.00	3 000.00	4 000.00	4
31	Electric lighting and power system	lump	.....	1 000.00	1 000.00	1 200.00	1
32	Installing motor-driven centrifugal pump	lump	.....	200.00	200.00	500.00	
	¾ Acre filter plus controllers for all filters and excavations for present uncovered filters	Total			$175 958.00		$171
	1 Acre filter plus controllers for all filters and excavations for present uncovered filters	Total			$208 708.00		$201

* Quantities for item numbers suffixed by the letter "A" are for increas
work under these items is considered additional work and can be inclu
apply is shown crosshatched in two (2) directions on the drawings.

† Quantities for item numbers suffixed by the letter "B" are for extendi
additional work and can be included or excluded at the option of the
direction on the drawings.

PLATE I.
N. E. W. W. ASSOCIATION.
VOL. XXXIX.
KNOWLES, MANSFIELD AND NUGENT ON LAWRENCE WATER SUPPLY.

	K J. Holland, St., Lawrence.	Louis C. Cyr, Saunders Bldg., Lawrence.		Simpson Bros. Corp., 77 Summer St., Boston.		Cenadella and Company, School St., Milford.		Joseph Long & Co., 29 Blossom St., Leominster.	
	Amount.	Unit Price.	Amount.	Unit Price.	Amount.	Unit Price.	Amount.	Unit Price.	Amount.
	$31 500.00	$1.15	$36 225.00	$.85	$26 775.00	$1.45	$45 675.00	$1.50	$47 250.00
	7 000.00A	1.15	8 050.00A	.82	5 740.00A	1.45	10 150.00A	1.50	10 500.00A
	2 100.00B	1.30	2 730.00B	1.00	2 100.00B	1.50	3 150.00B	1.75	3 675.00B
	2 000.00	7 040.00	7 040.00	1 920.00	1 920.00	4 500.00	4 500.00	400.00	400.00
	1 800.00	2.35	2 115.00	2.00	1 800.00	1.50	1 350.00	4.00	3 600.00
	400.00A	2.35	470.00A	2.00	400.00A	1.50	300.00A	4.00	800.00A
	27 500.00	14.65	20 143.75	13.50	18 562.50	13.50	18 562.50	25.00	34 375.00
	5 000.00A	14.65	3 662.50A	13.50	3 375 00A	13.50	3 375.00A	25.00	6 250.00A
	19 000.00	17.00	16 150.00	21.20	20 140.00	16.00	15 200.00	20.00	19 000.00
	3 500.00A	17.00	2 975.00A	21.20	3 710.00A	15.00	2 800.00A	20.00	3 500.00A
	3 500.00	20.00	3 500.00	34.00	5 950.00	25.00	4 375.00	30.00	5 250.00
	800.00A	20.00	800.00A	34.00	1 360.00A	25.00	1 000.00A	30.00	1 200.00A
	21 500.00	24.50	26 337.50	24.00	25 800.00	19.50	20 962.50	30.00	32 250.00
	5 000.00A	24.50	6 125.00A	24.00	6 000.00A	19.50	4 875.00A	30.00	7 500.00A
	14 800.00	.0485	17 945.00	.053	19 610.00	.07	25 900.00	.07	25 900.00
	2 720.00A	.0485	3 298.00A	.053	3 604.00A	.07	4 760.00A	.07	4 760.00A
	3 600.00	110.00	3 960.00	158.00	5 688.00	100.00	3 600.00	100.00	3 600.00
	3 000.00	250.00	3 750.00	370.00	5 550.00	225.00	3 375.00	240.00	3 600.00
	1 750.00	260.00	1 820.00	370.00	2 590.00	250.00	1 750.00	240.00	1 680.00
	400.00	700.00	700.00	660.00	660.00	3 500.00	3 500.00	700.00	700.00
	500.00	2 042.00	2 042.00	2 450.00	2 450.00	1 900.00	1 900.00	160.00	160.00
	600.00A	2 256.00	2 256.00A	2 760.00	2 760.00A	2 100.00	2 100.00A	190.00	190.00A
	500.00B1	2 042.00	2 042.00B1	2 450.00	2 450.00B1	1 900.00	1 900.00B1	160.00	160.00B1
	1 200.00B2	2 256.00	4 512.00B2	2 760.00	5 520.00B2	2 100.00	4 200.00B2	185.00	370.00B2
	600.00	254.00	762.00	420.00	1 260.00	225.00	675.00	200.00	600.00
	700 .00	230.00	920.00	330.00	1 320.00	200.00	800.00	200.00	800.00
	600.00	185.00	740.00	300.00	1 200.00	175.00	700.00	160.00	640.00
	250.00	132.00	264.00	190.00	380.00	125.00	250.00	85.00	170.00
	400.00	115.00	460.00	220.00	880.00	100.00	400.00	100.00	400.00
	340.00	70.00	280.00	130.00	520.00	80.00	320.00	60.00	240.00
	75.00	89.00	89.00	170.00	170.00	100.00	100.00	60.00	60.00
	75.00	66.00	66.00	120.00	120.00	80.00	80.00	55.00	55.00
	60.00	54.00	54.00	130.00	130.00	60.00	60.00	48.00	48.00
	3 750.00	25.00	150.00	18.00	108.00	25.00	150.00	28.00	168.00
	975.00	.45	877.50	.50	975.00	.65	1 267.50	1.15	2 242.50
	225.00A	.45	202.50A	.50	225.00A	.65	292.50A	1.15	517.50A
	36.00	.28	25.20	.40	36.00	.50	45.00	.85	76.50
	2 800.00	3.65	2 920.00	5.20	4 160.00	4.00	3 200.00	5.00	4 000.00
	630.00A	3.65	657.00A	5.20	936.00A	4.00	720.00A	5.00	900.00A
	15 000.00	2.10	15 500.00	3.60	18 000.00	3.25	16 250.00	4.75	23 750.00
	3 600.00A	3.10	3 720.00A	3.60	4 320.00A	3.25	3 900.00A	4.75	5 700.00A
	3 000.00	.165	2 475.00	.25	3 750.00	.20	3 000.00	.11	1 650.00
	700.00A	.165	577.50A	.25	875.00A	.20	700.00A	.11	385.00A
	2 000.00	1 500.00	1 500.00	1 850.00	1 850.00	2 500.00	2 500.00	2 000.00	2 000.00
	4 000.00	3 300.00	3 300.00	3 043.00	3 043.00	1 800.00	1 800.00	600.00	600.00
	1 200.00	800.00	800.00	1 150.00	1 150.00	2 000.00	2 000.00	1 200.00	1 200.00
	500.00	220.00	220.00	363.00	363.00	250.00	250.00	350.00	350.00
	$171 011.00		$182 414.95		$186 980.50		$193 747.50		$221 020.00
	$201 186.00		$215 208.45		$220 285.50		$228 720.00		$263 222.50

ncreasing the length of the proposed filter 5 bays, or 75 feet, to the east. The included or excluded at the option of the city. The area to which these items gs.

xtending the existing uncovered filters. The work under these items is considered f the city. The area to which these items apply is shown crosshatched in one

posed for Lawrence. It has been taken for granted that there was no reason why that which had proven reliable and efficient in the past should not be continued in the future. It is also of course realized that the State Department of Health would not approve any other type than that of the slow sand method; mechanical filtration, using coagulant, not being deemed advisable with the soft water of the Merrimac River.

Such estimates as have been made, however, for preliminary treatment indicate that there is no saving in the mechanical filter, when considering the costs of operation due to the use of chemicals.

Tabulation of Bids.

The tabulation of bids for various filter items, installed under the 1925 program, is presented in Plate I. It is of interest to note that, while the cost of the filter is somewhat greater than was at first estimated, this is not because of error in estimating the unit prices, but because of the greater amount of work advertised, due to the discovered conditions. It was found wise to do some more things in connection with the filter than was at first contemplated. This is because the acquirement of a new supply seems farther and farther away and that such new filter equipment and renovated units will have to operate somewhat longer than was first expected.

This all points toward the remodeling of the uncovered filters and cleaning out of the westerly covered filter, so that all of these units will operate effectively. This work should be done as soon as possible, in order that sufficient quantity of water can be obtained. Delay again will be dangerous.

Pumps and Boilers.

It has been evident for some time that the Leavitt pumps, erected in 1876, have long since outlived their usefulness. The senior writer made a report upon this subject in 1911 and then recommended the installation of new units, carrying the older pumps as reserve for spare service. These pumps, however, had given such excellent service and there was so much pride in their appearance and operation that there was considerable opposition to their discontinuance and removal from service. This arises not only from those who have pride in old and unique units and dislike to see such remarkable construction discarded, but also from some who view new expenditures as wasteful, while something still exists capable of doing any work at all. Bed plates in these pumps have been cracked from time to time and repaired. The upper bearings, in which the walking beams oscillate, have operated without Babbitt metal for as long as 15 years, and it is really remarkable that the pumps give as good service as they do. They speak in eloquent terms of the designer and the builders. It is probable that their great massiveness and good construction have aided materially in keeping them going in the face of the above circumstances.

It is now decided, however, that a new low-service unit shall be installed.

Because of the hope that it will not be too long before a new supply will be obtained, with the possibility, therefore, of doing away with some of the installation at the present pumping plant, and the desire to avoid unnecessary expenditure, it was decided to have the new pump a turbine-driven centrifugal pumping unit. This unit will be set in the pit on the west side of the pumping-room basement, so that the lift from the wet well will not be excessive when the filters are drawn down.

Such pump also would be capable of obtaining water out of the Water Street main and lifting it into the 16-in. high-service main running to the standpipe. Such connection, however, is not provided for at present, in view of the fact that there are several other units which can get water into high service with suction from other sources. Furthermore, the Water Works Superintendent has in mind putting in an auxiliary high-service pump, an automatic electric-driven unit, located at the reservoir, and which will pump directly into the standpipe.

Having this in mind, the low-service unit will be a 6 million gal. pump instead of one of 5 million gal. capacity, as might otherwise obtain if it were not for this contemplated new arrangement.

The pumping machinery has been somewhat handicapped in efficiency by not having steam furnished at sufficiently high pressure. The present boilers, while capable of running at 125 lbs. pressure, ordinarily operate at 100 lbs. This is not conducive to economy in operation of pumping units. It is planned that the new steam-turbine unit will have steam delivered at 150 lbs. pressure, and the new boiler therefore will operate at 160 lbs. Besides having direct connection to the new turbine-driven pump, there will be steam-pipe extensions to the existing steam lines leading to the other pumps, with pressure-reducing valves. This will permit steam to pass into all lines so as to operate the other pumps, even though the existing boilers be shut down.

Conclusions.

It is evident that we have an illustration of a people, so lulled in the supposed security of a safe, adequate water supply, that the usual agitation, and the presentation of facts, does not stimulate them to an appreciation of the needs sufficiently to appropriate money to make the required expenditures for new works. There is an additional contributing factor, viz., — that, for a long time the residence of an important member of the State Board of Health was within the city of Lawrence; advice and help was always available in abundance. The experimental work going on at the local station of the State Department of Health and a realization of the close observation of this department, with occasional corrective letters and admonition, have brought a lack of independence and self-assertiveness so necessary to solve questions by independent original action on the part of the electorate.

It is apparent that there is lethargy in Lawrence and a failure to realize the seriousness of the situation. Complications, too, have come from the fact that other cities and towns in the vicinity have needs which should bring about coöperation, and have served to delay individual action. Nevertheless, attempts to bring about this coördination and metropolitan action have also resulted in contributions to the delay.

We find a city of about 100 000 population, in which the amount of money spent for spring water equalled, at the time of the study in 1916, more than half the amount of revenue obtained from water-rate payers. It was due not to a lack of safety and healthfulness in the city water, but to disagreeable tastes and odors which made the water objectionable. The result was that the people bought water which frequently was no safer, and sometimes not so safe, from the health point of view.

We find a community, with the usual situation of lack of funds for its many public needs, but still finding ways to raise money for many things not so seriously required as a sufficient supply of water. All of this has brought about procrastination. There is one unique factor which does not usually obtain: Nowhere else can water be obtained from a neighboring town practically without even asking leave. It is simply expensive, but expense is not sufficient to cause people to plan wisely. There must be a more compelling arousing of public spirit.

It is recognized by those who know, that the present work is one of emergency only and may be of quite temporary character. The growth of urban communities in eastern Massachusetts is so great that the need of water supplies and the increasing lack of sufficient water is a most important public question. Legislative committees have considered the subject and will probably continue so to sit and study. It is one of the great problems of the built-up sections of this country.

It is sincerely to be hoped that some way may be found to promote state comity, so that a means may be developed for utilizing waters which are available, but which are over the state lines. The presentation of this paper may be considered to be pointed equally as sharply toward an attempt to arouse intelligent discussion of these problems, as toward a description of the interesting works of the older type which is now becoming rare in the newer parts of the country and particularly where waters are muddy. The authors will be pleased if the attempt brings about some stimulating argument with regard to the means of caring for the growing needs of urban communities with the disappearance of available water supplies.

Discussion.

President Taylor. This is a very interesting paper on a timely subject, and brings out vividly, as Mr. Knowles has said, some of the difficulties that are encountered in getting bonds for burying pipes which are never seen again, and people do not fully appreciate what they have under-

ground. Mr. Knowles suggests discussion, and I hope there will be a full discussion of the paper. We shall be glad to hear from anyone who will discuss it.

JOHN F. LABOON.* May I ask Mr. Knowles what is the rate of capacity of his filter, and just what it will cost per million gallons?

MR. KNOWLES. The cost, you will remember, is $175,000. Ordinarily the filters are designed for the rate of two million gal. per acre. They will operate at three, and the present ones have, but the recommended rate is two. There is no settling basin. The pond of the river formed by the dam, about three-quarters of a mile below, does furnish some sedimentation facilities. Yet, in the springtime, the water is somewhat silty, even muddy. It is highly polluted. It is one of the highly polluted rivers of the country.

PAUL HANSEN.† May I ask Mr. Knowles what consideration led to the adoption of the slow sand filters?

MR. KNOWLES. I take it, in answer to Mr. Hansen, we ought to remember the history, and, — as I said in passing, — that we have a unique situation at Lawrence. It was the home of Hiram F. Mills, late honorary member of this Association, who was a member of the Water Supply Committee of the State Department of Health. He was very much wrapped up in the subject. He caused to have built the experiment station at Lawrence, Mass., which has been so important an adjunct in the development of sanitary engineering in this country. The early experiments led the department to believe that sand filtration was safe.

These were the days before mechanical or rapid filtration was used except as strainers in paper mills, and before there were any rapid filters as we know them now. And there was something of an adverse feeling in New England, with our soft waters, towards anything called dosing the water. But a good deal of water has gone over the dam since those days. We now put chlorine in the water; as Mr. Clark mentioned in his paper, we think of putting iodine in the water. And we put copper sulphate in the water to get rid of algae growths.

But nevertheless, we have the situation in which sand filters were built by the foremost and most prominent men in the world on the subject at that time. They were successfully used and saved the lives of the people. You have a situation, therefore, in which it is not easy to think of using the later designs of filters, which have been used in the West and used with muddy waters and used with waters which are hard, to which this water does not correspond to any extent.

But incidentally, I may say, because that is perhaps more to the point, in answer to Mr. Hansen's question, that last year we did investigate the case of putting in what would be called pre-filters, working them rapidly, for the purpose of running the final filters at a faster rate; and also independent mechanical filters were considered. But, partly due to the neces-

* Of The J. N. Chester Engineers, Pittsburgh, Pa.
† Of Pearse, Greeley & Hansen, Consulting Engineers, Chicago, Ill.

sity of joining up with the old ones, — I will not attempt to say what it might be if one were to start *de novo* and had an entirely new plant, with new arrangements, — but under the particular arrangements of fitting in, there is no saving in building mechanical or rapid filters.

EDWARD G. BRADBURY.* Mr. Knowles spoke of the large amounts of money spent for spring water as compared with the public water supply. This is frequently due to prejudice on the part of the public. In Columbus, Ohio, after the filter plant was constructed some years ago, large quantities of spring water continued to be sold, and it was discovered by the water department that some of the dealers in spring water were filling their tanks and bottles from the city water supply and selling at five cents a gallon to the public, and the customers were perfectly satisfied with it.

Another instance was that of a photographer who filed a complaint with the city that his films were spoiled by the chemicals used in treating the water at a time before any treatment of the water had been started.

PRESIDENT TAYLOR. Mr. Mosteller told me a very interesting story about spring water. Would you mind telling it?

W. P. MOSTELLER.* I did not know that anyone could tell an interesting story about water. The story your President refers to is of a farmer who had a very large spring on his property, and illustrates very well the point in question that the city dweller does not appreciate the good water furnished him by our water departments.

He and his two sons had developed a large business in selling water to a nearby city. The interesting story is that there was a pipe line running along a country road near his farm. This pipe line was not in general use and had been tapped only in a few places to give water to neighboring farms, and since the line was so little used the water department decided to abandon this pipe line and accordingly the water was shut off one day. This pipe line belonged to a water district covering a very large area near a large city, and in the course of time a real estate company, in developing the area, wanted to buy this farm and cut it up into building lots.

An attempt was made to buy the farm but no offer was acceptable to the farmer on account of this very valuable spring, and every time the matter was broached the spring was given as a reason why an increase was added to the price of the farm, but when this pipe line was shut off the spring disappeared and the farmer's business was closed out. The farmer then attempted to enter suit against the water district controlling the pipe line to recover damages for their interference with his spring, which was his source of livelihood. The commission's engineer then investigated the pipe line and found that it had become disjointed and that it had probably been leaking in several places for a good many years, and our friend of course had to withdraw his complaint.

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* County Sanitary Engineer, Columbus, Ohio.
* Of United States Cast Iron Pipe & Foundry Co., Burlington, N. J.

THE NEW LITTLE QUITTACAS INTAKE AT NEW BEDFORD, MASS.

BY F. A. BARBOUR.*

[*Read November 10, 1925.*]

This paper describes the design and method of constructing the additional intake conduit into Little Quittacas Pond, built in 1923 and 1924, under the general direction of Mr. Stephen H. Taylor, Superintendent of the New Bedford Water Department.

The immediate reason for an additional intake was the risk of stoppage by ice of the single connection between the pumps and the source of supply. Another reason lay in the fact that there had developed a transverse crack across the old masonry intake conduit, which it was believed could not be repaired without shutting down the pumps for such a period as might result in serious depletion of the water stored in the distribution reservoir on High Hill. In more general terms, the provision of a second intake was a consistent development of the established New Bedford policy of duplicating all essential parts of the water system so as to guard against accident of any kind.

The first intake into Little Quittacas Pond, built in 1896–1899 under the able supervision of Rice and Evans, engineers, is a basket-shaped (5 ft. by 5 ft.) brick conduit which extends from the pump well, under the station, 450 ft. easterly into the pond, and terminates at a point where, because of exposure to the full sweep of the northerly winds across the pond, the surface ice is slow in forming, and where the drift of frazil, or needle ice, and of grass and other suspended matter, stirred up by wind action in the relatively shallow water, is readily intercepted.

In the old intake tower, a motor-driven, belt type screen of $\frac{1}{16}$-in. woven copper wire, four meshes to the inch, 5 ft. 6 in. wide, traveling at a speed of 6 in. per minute and cleaned by water jet, had been installed in 1908. This screen, credit for the design of which is due to the late Mr. A. S. Negus, engineer at the pumping station, and to Mr. Coggeshall, had under certain conditions of wind and temperature been so clogged by frazil ice as to necessitate the stopping of the pumps for periods ranging from a few hours to a full day. These interruptions of service apparently were caused by the driving of the needle ice by northerly winds into the cove to the south of the intake and by the filling of this cove under the long-continued blow so as to submerge the intake in the accumulated slush.

In all of the twenty-six recorded occasions when ice had interfered with the operation of the pumps, the wind was in a northerly quarter, or

*Of Barbour & Dixon, Consulting Engineers, Boston, Mass.

To Middleboro
LITTLE QUITTACAS POND
High Water E
New Intake Tower
New Old Intake Conduit
New Screen Chamber
Old Intake
PUMPING STATION
NOTE - Contour

PLATE I.
N. E. W. W. ASSOCIATION.
VOL. XXXIX.
BARBOUR ON
QUITTACAS INTAKE.

NEW BEDFORD WATER WORKS
ADDITIONAL LITTLE QUITTACAS INTAKE
GENERAL PLAN OF
LITTLE QUITTACAS POND
SHOWING LOCATION OF INTAKE

0 500 1000 1500 2000 3000
SCALE OF FEET

1925

Stephen H. Taylor
Supt of Water Works

Barbour and Dixon,
Engineers

across the long stretch of exposed water surface, the wind velocity generally in excess of twenty miles per hour, and with an air temperature ranging from zero to the freezing point.

In addition to ice interference, grass and vegetable slime, swept toward the intake by wind action, had on some sixteen occasions so clogged the slow-moving screen as to make it necessary to stop the pumps.

While the total number of occasions when the pumps had been stopped by ice, and by roiling of the pond, had not been great, it was thought — since the tendency to draw ice particles into the intake depends on the inlet velocity — that the periods of ice interference would increase at some higher rate than the increase in consumption and that it was, therefore, wise to provide an additional intake to draft water from a point well away from the south cove and under a lee shore which might serve as a protection against the northerly winds and facilitate the early formation of surface ice, which is the best-known preventive of the objectionable needle ice.

The point of intake, selected by Mr. Taylor (see Plate I), is under the lee of a small island and in a part of the pond where the surface is reported to freeze over early and remain frozen, when there is any ice on the pond.

General Design of Intake.

After consideration of various alternative possibilities, it was decided to follow in general the design of the intake built in 1896–1898, and to construct the new intake so as to permit unwatering of the conduit for inspection, cleaning, and repairs, with an intake tower at the outer end and a screen chamber and house on shore adjacent to the pumping station. A diameter of 60 in. was chosen, based on a total available head through the intake ports, screen, and conduit of 1.5 ft., this head being the difference in elevation between maximum probable draw-down of the pond and the elevation in pump well required for a 4-ft. submergence of the suction pipes. With this head, the capacity of the conduit is approximately 35 million gal. per day, or equal to a pump rate 50 per cent. greater than the anticipated average consumption in 1950. A 54-in. diameter would have saved ten per cent. of the cost of the conduit, not including intake tower and screen chamber, but would have reduced the capacity 25 per cent. A much more important factor in fixing relative cost was the decision to construct an intake which could be unwatered for inspection and cleaning. This made necessary the intake tower and the loading of the conduit against flotation, involving an outlay of approximately $50 000 more than would have been required for a conduit of the same size and material with submerged crib or intake and not designed for unwatering. The shallowness of Little Quittacas Pond, the tendency of the wind to stir up the bottom sediment, and the rapid growth of fresh-water sponge made accessibility for cleaning and inspection more important than under other conditions. The underlying reason for the adoption of this unwaterable type of structure, however, was the established standard of the New Bedford Water Department

that all essential parts of its physical plant shall be as good as they can be made within reasonable limits of economy. Such a standard was adopted by Rice and Evans in the excellent work done by them in the redevelopment of the New Bedford supply, and has been continued to date. That it has been justified is well evidenced by the general efficiency and morale of the department and the regard of the citizens of New Bedford for their water system.

The Conduit — Design and Specification Requirements.

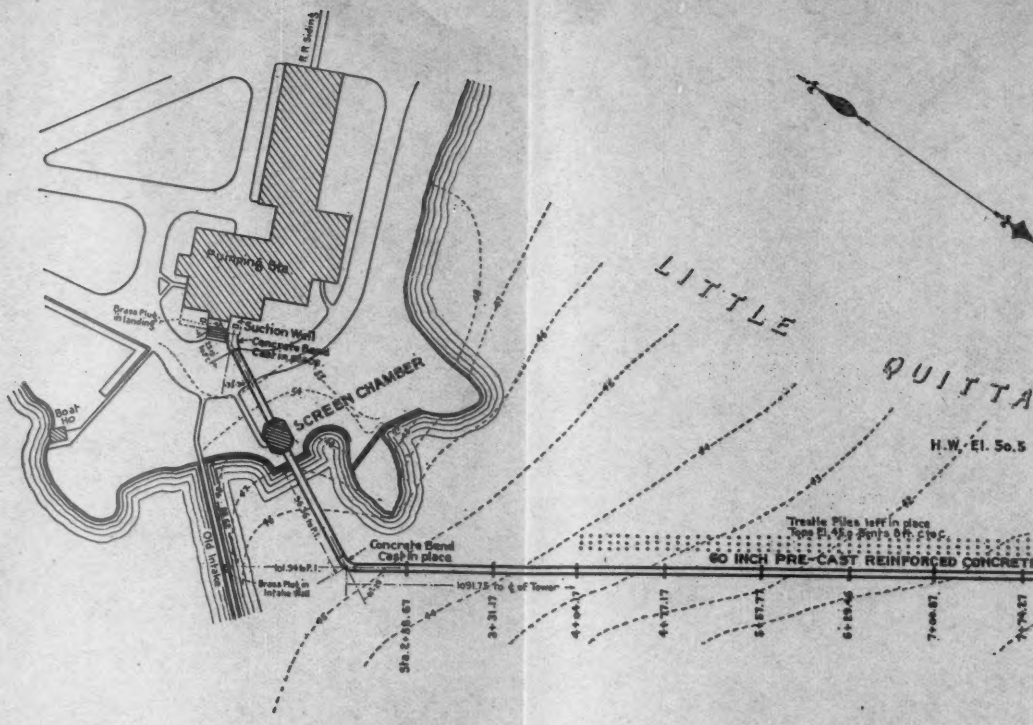
As will be seen by reference to Plate II, the conduit for a distance of 220 ft. is laid due north from the pumping station, at which point it turns to the northwest and runs for a distance of 1 080 ft. to the intake tower, this alignment — instead of a direct course from the pump well to the point of intake — being chosen in order to avoid deep rock cutting in the hill adjacent to the station, and to get the trench away as quickly as possible from the station foundations, which were reported to have been in quicksand.

At a point about 80 ft. from the station, the screen chamber was located and, to support the grading around the screen house, a retaining a wall of concrete, faced by granite rubble, was constructed to form a new shore line.

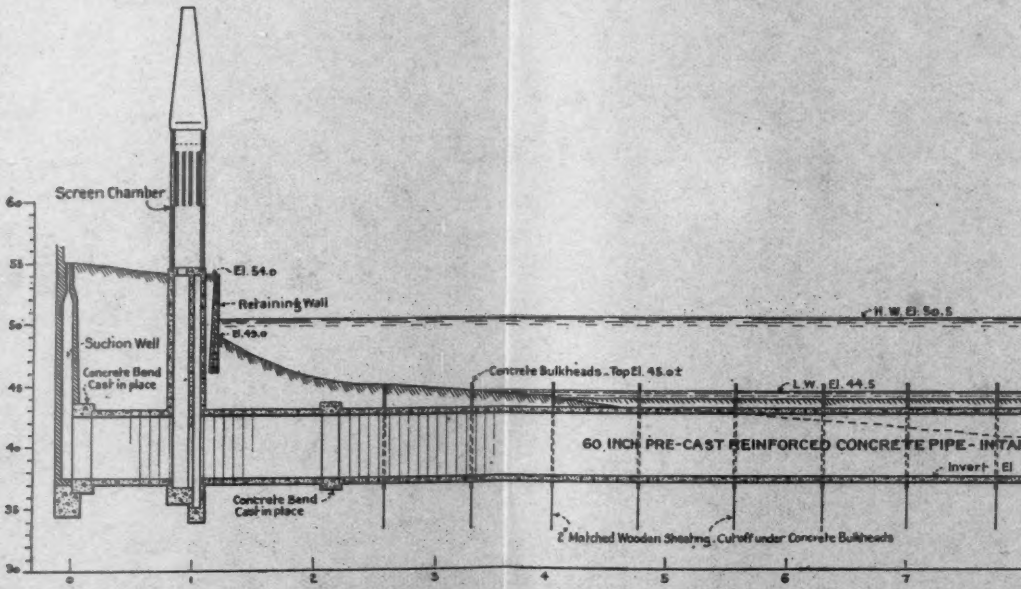
The invert of the conduit was laid level at elevation 37.5 (see Plate II), which placed the pipe on solid pond bottom at its outer end at the intake tower, and brought the top of the conduit to elevation 43.0, or 1 ft. below the minimum level of pond draw-down, and thus free from possible derangement by ice action.

Concrete pipe was selected for the conduit on the basis of relative cost, permanence, and freedom from tuberculation. At the then obtaining price of cast iron of $65 per ton, the cost of this type of pipe was approximately 75 per cent. more than that of concrete pipe.

Specifications were prepared for precast concrete pipe, and bids were invited on the same day as for the construction contract, in which latter there were required proposals for laying the precast pipe and also for building a conduit of poured-in-place concrete. It is of interest to note that three of the four construction bidders submitted prices which showed a margin in favor of poured-in-place concrete ranging from $12 000 to $20-000, or approximately of from $10 to $16 per ft., while the fourth contractor favored the precast pipe by $48 000, or $40 per ft., bidding a price for laying which brought this latter type of conduit within $9 000 of the lowest price named for poured-in-place concrete. In the belief that a better pipe can be cast in vertical forms on dry ground than horizontally in a trench with a bottom which at any moment might show an uncontrollable desire to vomit, and because it might prove necessary to lay the pipe under water, precast pipe was selected and purchased from the Lock Joint Pipe Company at the following prices: 60-in. pipe, $18 per lin. ft.; lead gaskets, $4.50 per gasket; tie bolts, $4 per set for one joint.



GENERAL PLAN



NEW BEDFORD WATER BOARD

ADDITIONAL LITTLE QUITTACAS INTAKE

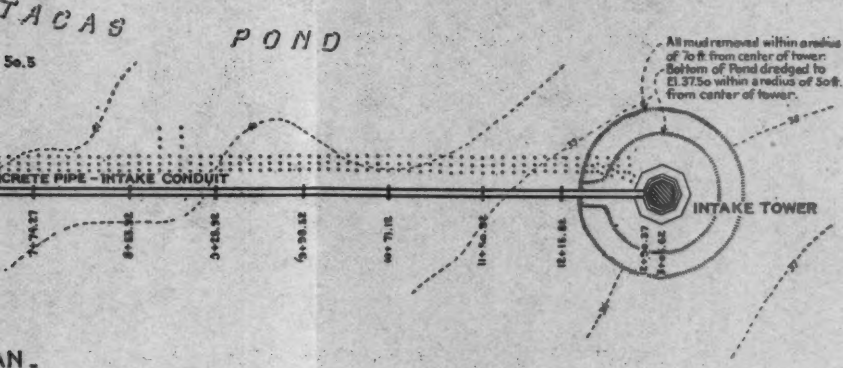
GENERAL PLAN AND PROFILE

Scale in Feet

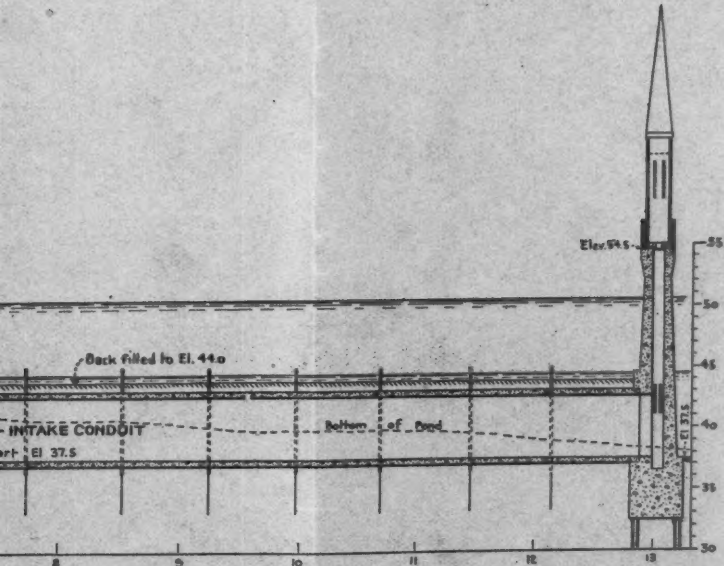
March, 1925.

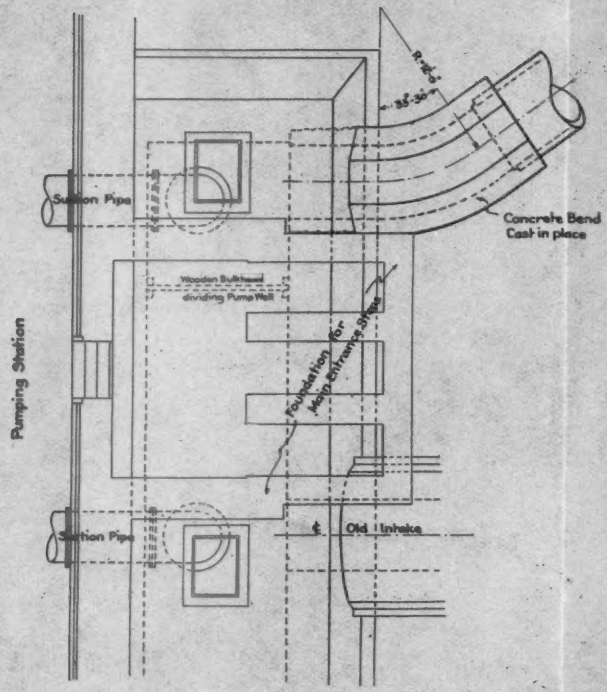
Stephen H. Taylor,
Supt of Water Works

Barbour and Dixon,
Engineers

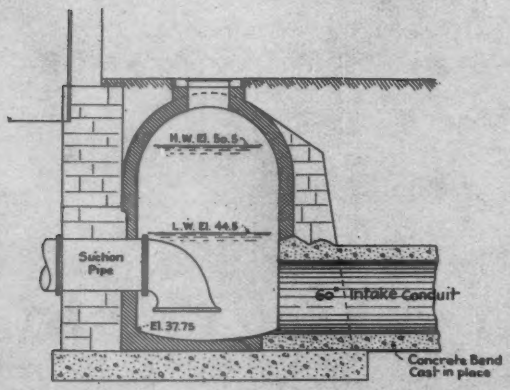

TACAS
POND
All mud removed within a radius of 70 ft. from center of tower. Bottom of Pond dredged to El. 37.5o within a radius of 5oft. from center of tower.
CRETE PIPE - INTAKE CONDUIT
INTAKE TOWER

AN -





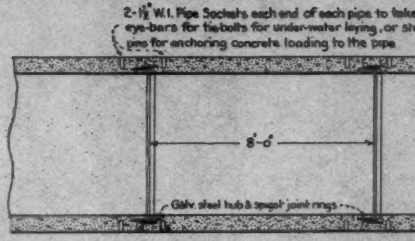
-PLAN-



-SECTION-

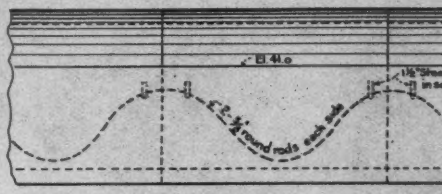
-DETAIL OF CONNECTON WITH SUCTION WELL-

Scale in Feet


2-1½" W.I. Pipe Sockets each end of each pipe to take eye-bars for tie-bolts for under-water laying, or sh
pins for anchoring concrete loading to the pipe
8'-0"
Galv. steel hub & spigot joint rings

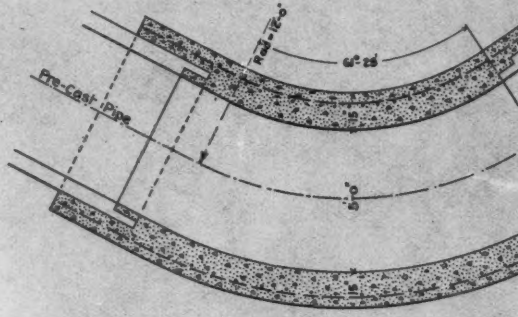
LONGITUDINAL SECTION

-DETAILS To



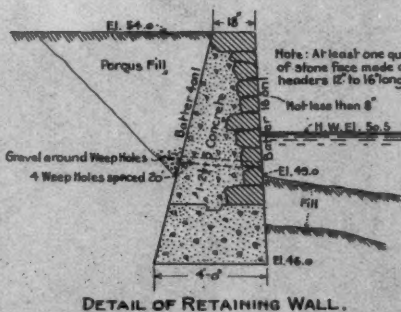
LONGITUDINAL ELEVATION

-CONCRETE LOA

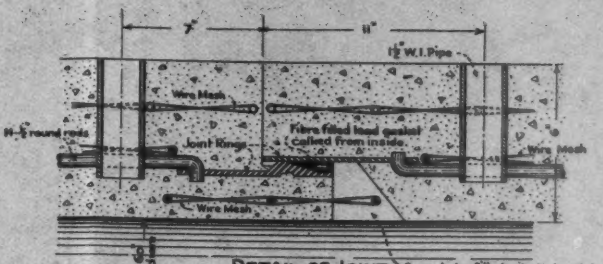


SECTIONAL PLAN

-DETAILS

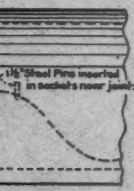


DETAIL OF RETAINING WALL.

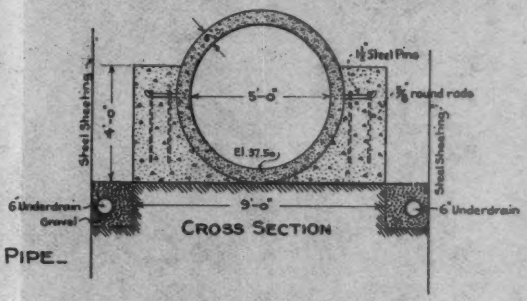


TAILS OF PRE-CAST CONCRETE PIPE.
TO BE FURNISHED BY THE CITY.

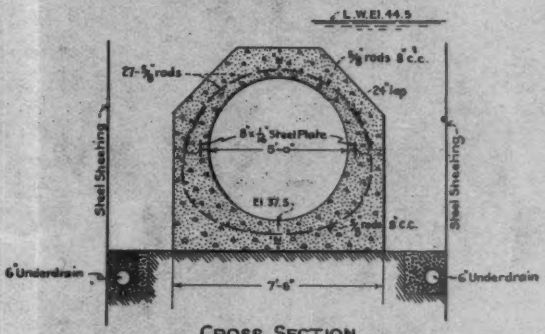
DETAIL OF JOINT. Space to be filled with Hot mortar
No Scale.



LOADING OF PRE-CAST PIPE.



CROSS SECTION



CROSS SECTION

LS OF CAST-IN-PLACE CONCRETE BEND.

NEW BEDFORD WATER BOARD

ADDITIONAL LITTLE QUITTACAS INTAKE

DETAILS OF CONDUIT

Scale in Feet Except as Shown

March, 1925.

Stephen H. Taylor,
Supt. of Water Works

Barbour and Dixon,
Engineers.

The pipes were made in 8-ft. lengths with a shell thickness of 6 in. The joints were male and female, of the type shown on Plate III, formed of galvanized steel rings securely anchored to the steel framework of the pipe and designed for the use of a made-up lead gasket to be calked from the inside.

The pipes are reinforced with a double cage of wire mesh, providing not less than .360 sq. in. per lin. ft. and by 14–½ in. longitudinal bars distributed between and wired to the inner and outer cages, the bars of the inner cage to be attached to the steel joint rings. The wire mesh reinforcement of the inner cage projected at the spigot end to assist in bonding the mortar joint to be formed after laying the pipe.

The concrete was a 1-1½-2½ mix of cement, sand, and aggregate, the latter ranging from ¼ to ¾ in. in size of particle.

The pipes were cast vertically in steel forms and steam cured. The gaskets are fibre-filled lead, soldered in continuous rings of the proper length. Near each end of each pipe two 1½-in. nipples were set on a diametral line at right angles to the axis of the pipe for the insertion of eye-bars through which to pass the tie bolts used in drawing the pipes together.

The construction contractor was required to guarantee that the leakage in the conduit would not exceed three gal. per ft. of pipe per 24 hrs., equivalent to approximately 250 gal. per in. mile per 24 hrs., with an average head of 10 ft. on the center of the pipe. As the contractor could not be expected to know the possible tightness of the precast pipe and joints, it was stated in the construction contract, and also specified in the pipe contract, that the leakage under 10 lbs. pressure in a test to be made by the pipe contractor at the site of the work, by joining two 8-ft. lengths together and bulkheading the ends, should not exceed 100 gal. per in. mile per 24 hrs. The test showed a leakage approximately equal to two-thirds of the specified limit — practically all of which came through the concrete and not through the joint, and was gradually reducing during the period in which the water was held in the pipes.

It was further specified in the pipe contract that the manufacturer should furnish for a period of ten days an experienced mechanic to instruct the construction contractor in the laying of the pipe and the making of the joints.

The 60-in. concrete pipe, with walls 6 in. thick, weighs 1 210 lbs. per lin. ft., while the water displaced weighs 1 770 lbs., giving a net buoyancy of the empty pipe submerged in water of 560 lbs. per lin. ft. In order to permit unwatering of the conduit for interior inspection and repair, it was, therefore, necessary to load the pipe to prevent flotation. This was done by encasing the pipe for the lower two-thirds of its diameter in concrete, as shown on Plate III. The complete loaded section has a weight in air of 3 450 lbs. per lin. ft., figuring concrete at 140 lbs. per cu. ft., and a displacement with pipe empty of 2 770 lbs., thus providing a net weight when submerged of 680 lbs. per lin. ft., and a factor of safety against flotation of 1.24.

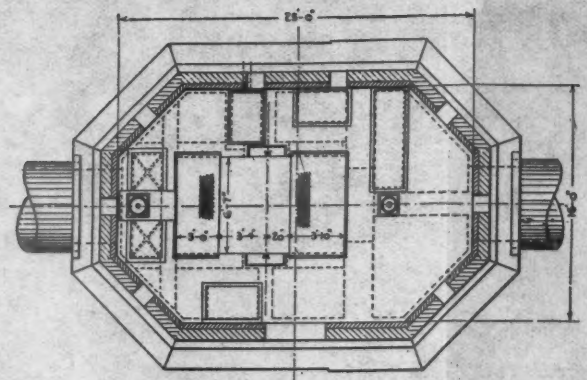
In order to develop sufficient bond between the pipe and the anchor concrete, an adhesive force of only 0.7 lb. per sq. in. on the projected external diameter of the pipe is required, while double that adhesion would lift the anchor concrete in water. Adhesion alone should therefore furnish ample bond, but for safety a hooked steel pin $1\frac{1}{2}$ in. in diameter, and projecting about 12 in. into the anchor concrete, was set in each of the four pipe nipple-lined holes provided for the insertion of the tie-bolt eye bars, and over these hooked pins two lines of $\frac{5}{8}$ in. reinforcing rods were draped longitudinally, as shown on Plate III. This reinforcement will suffice to prevent flotation, if complete rupture of the adhesive bond between the anchorage bond and the outside of the pipe should take place.

In preparing the construction contract, it was anticipated that because of the danger of undermining the foundations, it might prove advisable for the city to undertake with its own employees the building of the inshore section of the conduit and, accordingly, the contract was divided into two parts, the first covering the work from the station to the screen chamber, and the second from and including the screen chamber to and including the intake tower; with the provision that the contract as let might cover the entire work, or only the offshore section.

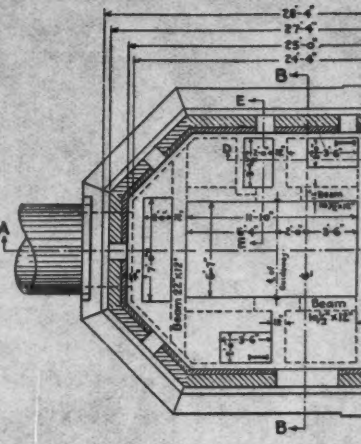
The work between the station and the screen chamber was let under the items usual in sewer contracts, such as cu. yds. of excavation between certain depths, rock excavation, and lin. ft. of pipe-laying. In the offshore section, however, and because of various methods which might be adopted by the contractor in laying out and planning the job, the conduit was paid for, both in the case of precast pipe and poured-in-place concrete, by the lin. ft., the prices to include the furnishing of all materials (except the precast pipe), excavation, back-filling, or otherwise disposing of the excavated material, the laying of the pipe, the loading of the pipe with concrete, and all incidental work, such as the construction of trestle, the removal of temporary timber work, underdraining of the trench, sheeting and pumping.

It was specified that the section of the conduit between screen and intake chambers must be laid in an unwatered sheeted trench, unless conditions as developed by trial rendered this, in the opinion of the engineer, impracticable. For the section adjacent to the pumping station, it was required, in order to discount the risk of undermining the foundations, that steel sheeting, in lengths satisfactory to the engineer, should be provided; that the work should be begun at the screen chamber, and that by sufficient pumping equipment the water table should be lowered so as to reduce the unbalanced pressure on the trench before undertaking any excavation immediately adjacent to the station.

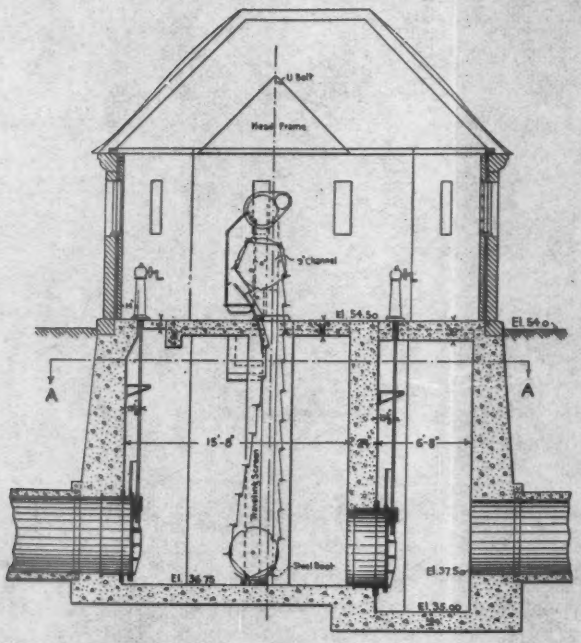
Since the new conduit left the shore of the pond at a short distance from the point where water would be continuously drafted through the old intake for the use of the city, it became necessary to prevent all pollution and, so far as possible, all roiling of the pond. It was, therefore, specified that all excavation within the pond limits, except dredging around intake



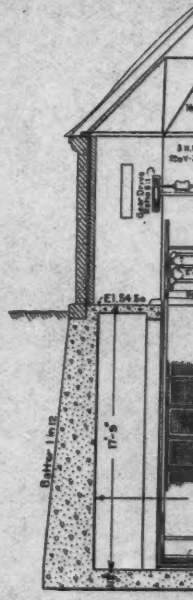
FLOOR PLAN



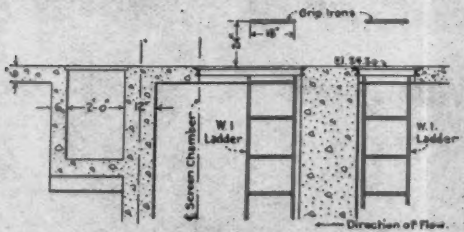
FLOOR PLAN WITH MASON



LONGITUDINAL SECTION A-A

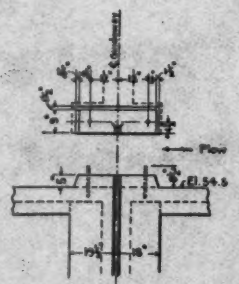


TRANSVERSE



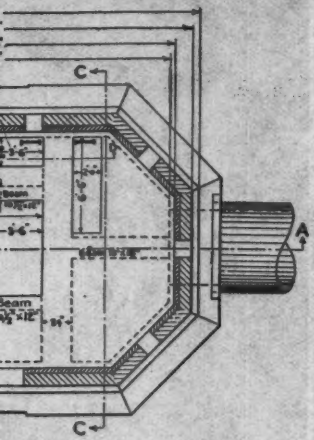
SECTION D-D THROUGH TRASH SUMP

0 1 2 3 4 5
Scale in Feet

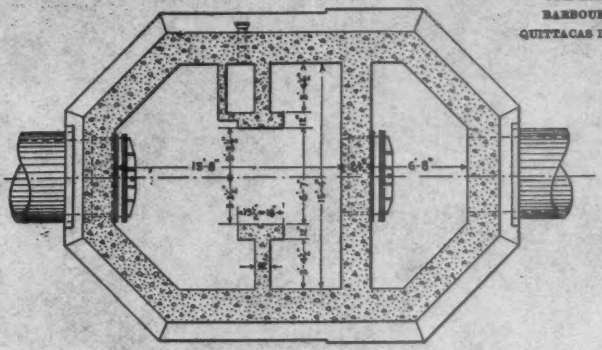


DETAIL OF FOUNDATION BOLT SETTING

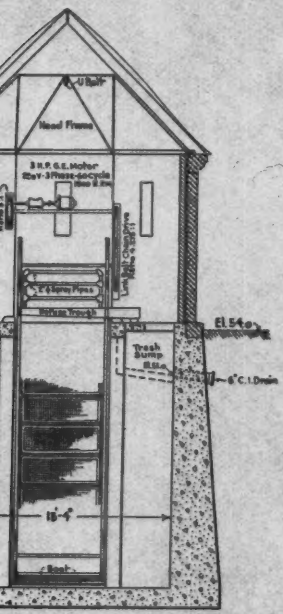
0 1 2 3 4 5
Scale in Feet



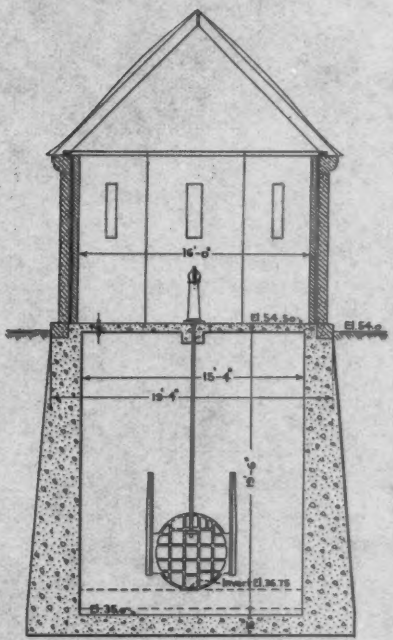
ASONRY DIMENSIONS.



SECTIONAL PLAN A-A



ERSE SECTION B-B.



TRANSVERSE SECTION C-C.

NEW BEDFORD WATER BOARD

ADDITIONAL LITTLE QUITTACAS INTAKE

GENERAL DRAWINGS OF SCREEN CHAMBER WITH DETAILS OF SUBSTRUCTURE

0 5 10 15

Scale in Feet Except as Shown

March, 1925.

Stephen H Taylor.
Supt of Water Works.

Barbour and Dixon,
Engineers

chamber, must be done within sheeting and that, similarly, all backfilling within the pond must also be placed inside of sheeting, except in case of excavation under water by suction dredge became necessary, under which conditions the material was required to be deposited on shore through a tight pipe line.

It was further specified that no wooden sheeting or pile within 8 ft. of the center line of conduit could be withdrawn, and that all temporary piling should be cut off 2.5 ft. below the elevation of maximum draw-down of the pond.

Underdrains surrounded by 8 in. of clean, screened gravel, ranging in size from ¼-in. to 1½ in., were provided for, and pump wells, which were to be frequently shifted so as not to draw the water through too great a distance, were permitted within the limits of the trench, with the requirement that all such sumps should be carefully refilled with selected gravel. The angles in the pipe line near the pumping station and beyond the screen chamber were made with poured-in-place reinforced concrete, in section as shown on Plate III.

The Screen Chamber and Screen.

As already stated, the screen chamber and house (see Plate IV) was located on the shore adjacent to the pumping station.

The substructure is of reinforced concrete — an elongated octagon in plan — divided by a cross wall into two compartments, the first of which forms a pump sump to facilitate drainage of the conduit, and the second a chamber for the installation of the mechanically operated screen. In the cross wall and over the conduit opening toward the station, sluice gates were set to make possible the isolation of the screen chamber without unwatering either section of the conduit.

The superstructure (see Fig. 1) is faced with random-coursed ashlar granite, lined with brick and roofed with red slate.

As already stated, the belt type screen had been in use for some fifteen years, and the satisfactory results of its operation led to the decision to install in the new intake similar equipment.

Proposals were accordingly invited for the furnishing and erecting in place of a motor-driven screen complete and ready for operation and including a frame truss for support of the tackle necessary in erection or dismantling. Bids were submitted by the Chain Belt Company and the Link Belt Company, the prices being $2 875 and $2 800 respectively. The contract was awarded to the lower bidder.

The specifications were limited to more or less general requirements in order that both manufacturers might offer their standard product. The following excerpts from these requirements will serve to describe the equipment, and may be of some general interest:

The screen shall consist of a series of panels of copper wire cloth screening carried on continuous chains, travelling over large sprocket wheels,

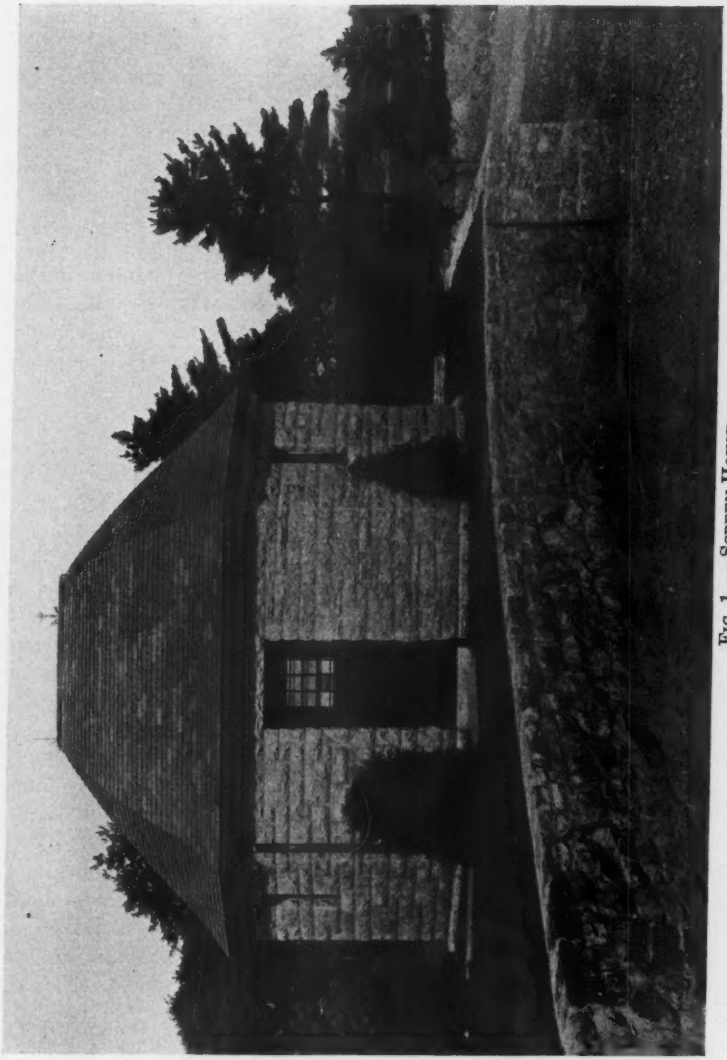


FIG. 1. — SCREEN HOUSE.

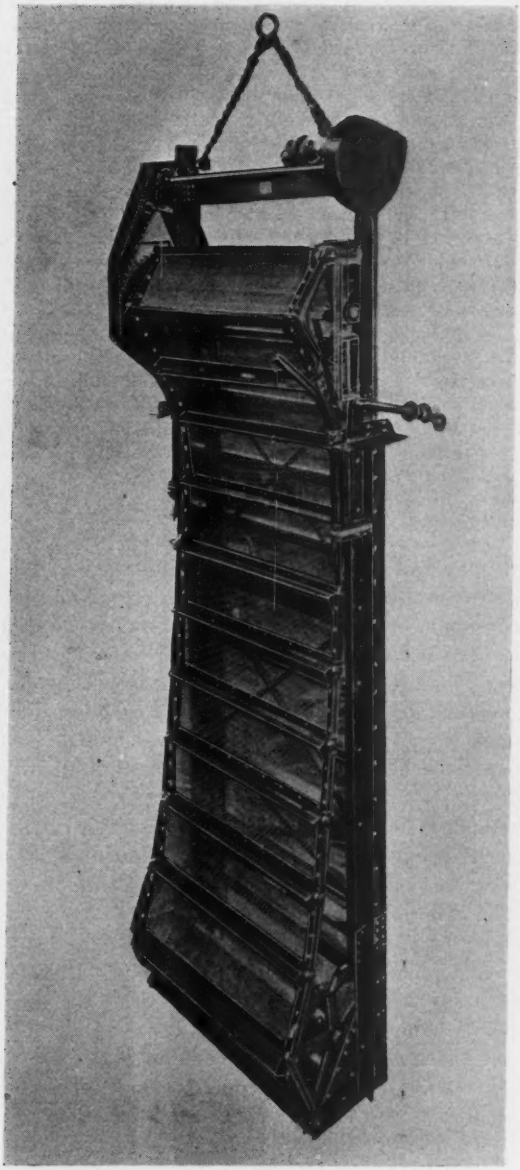


FIG. 2. — LINK BELT TRAVELLING WATER SCREEN.

driven by electric motor through speed-reducing machinery, the whole mounted in self-contained manner on a rigid vertical steel frame provided with flanges engaging in vertical guide grooves in the walls of the screen well so that the unit may be raised or lowered in the well without disturbing the masonry. The screen shall travel up on the influent side, each panel being provided with a lifting shelf or bucket to catch and raise the intercepted trash which shall be removed from the screen by streams of water under pressure from a suitably placed spray pipe.

The screen shall be constructed of No. 12 B. & S. gage copper wire mesh, with $\frac{1}{4}$-in. clear spaces, made up into panels of such width that there shall be at least thirty (30) sq. ft. of wire cloth effective for the passage of water below elevation 44.0 and above the top of the boot. Panel frames shall consist of welded steel plates, or angles, and the wire mesh shall be secured in place with galvanized steel bar straps bolted to the panel frame, with Sheradized bolts, washers, and nuts.

The frames shall be self-contained and divided into sections not exceeding ten (10) ft. in length for convenience in assembly in the screen well.

A steel plate boot shall be provided at the bottom of the screen for preventing the entrance of refuse beneath, and the details of construction shall be such that there is no opportunity for passage of refuse between the frame and the guides, between the screen baskets and frame, or between the screen panels themselves.

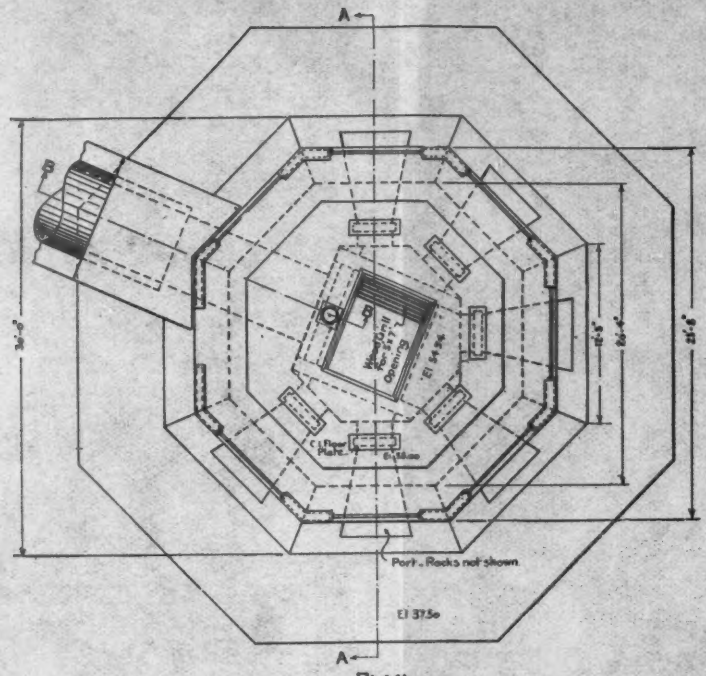
The speed of the screens shall be selected by the manufacturer to give best efficiency, but shall not exceed ten (10) ft. per minute.

The "traveling water screen," as furnished by the Link Belt Company, consists of a structural steel framework carrying head and foot sprockets over which runs on either side a double link, 24-in. pitch, bronze-bushed, steel roller chain, to each inside link of which there is attached a screen panel frame of 2 in. x 2 in. x $\frac{3}{16}$ inch steel angles, carrying the copper wire cloth, together with spray pipes, splash plate, and drip opening, and mounted on top of the main frame a 3 phase, 220 volt, 1 760 r.p.m. motor, driving through reduction mechanism the screen at a speed of $10\frac{1}{2}$ ft. per minute. (See Fig. 2.)

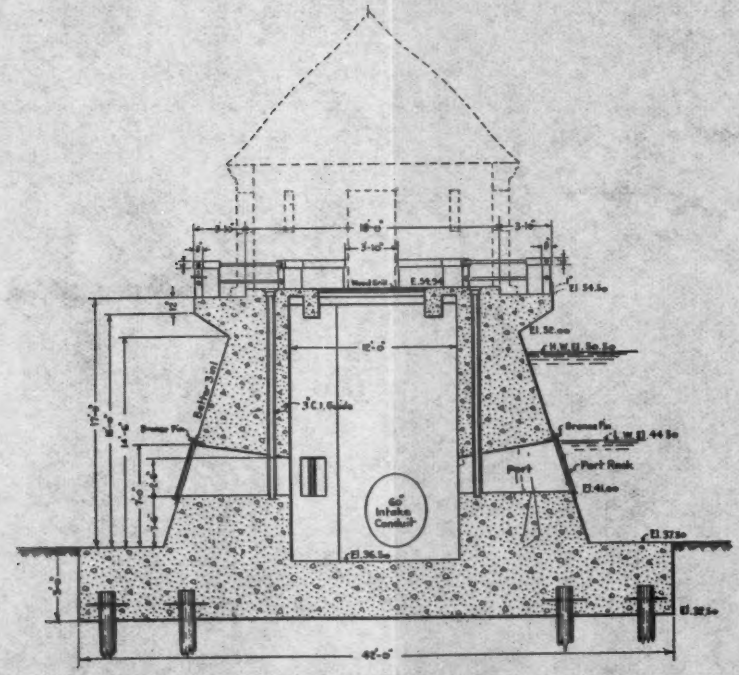
The outstanding features in the design of the Link Belt Company's screen are the steel angle panel frames and the inward slope of the down run of panels at the point of spraying. Because of the use of steel angle panel frames, a wider screen must be provided for the same net area of screen cloth than where flat plate frames are used.

An important point in the design of mechanically driven screens for municipal water supplies is the necessity of limiting the clearance on the sides and at the bottom between panels and boot to the dimensions of the openings in the screen cloth. As first erected at New Bedford, the panels in passing the boot left openings exceeding $\frac{3}{4}$ in. in width across the bottom and more than this at the rounded panel corners, or such as would in considerable measure negative the value of the screen as a bar to small fish and eels. This was corrected by the placing of a steel plate liner in the boot.

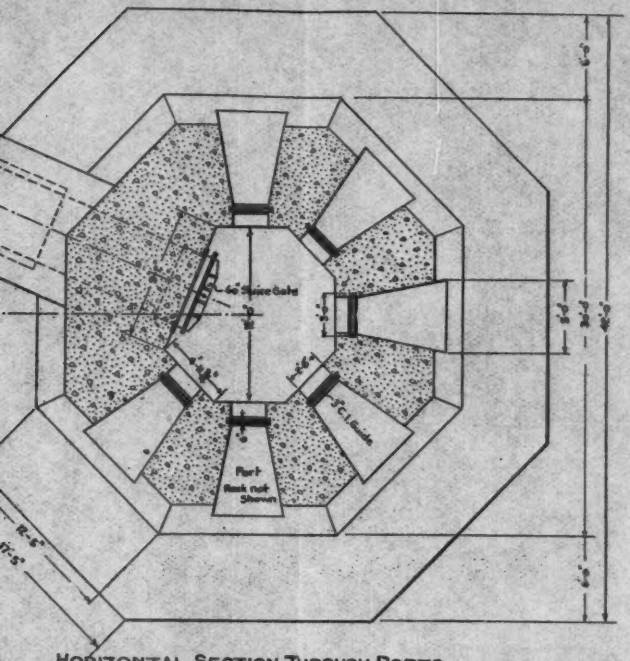
The power required for operation of the screen, when clean, is 1.12 kw. Assuming 1.5 kw. as the average demand, the cost of the electric energy



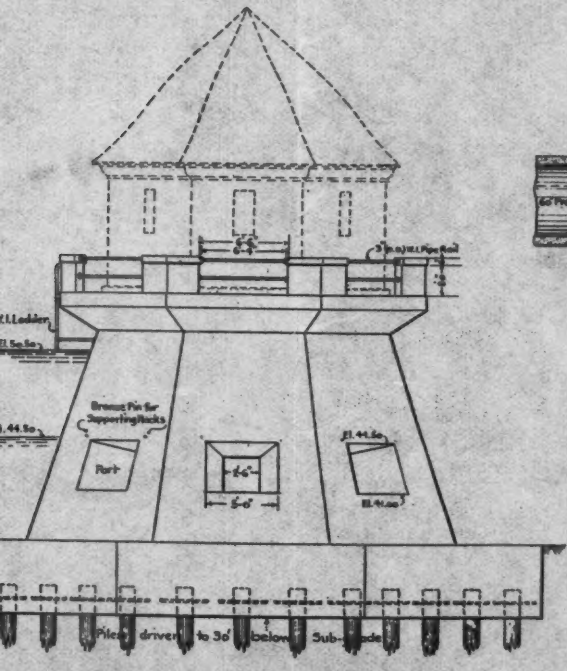
- PLAN -



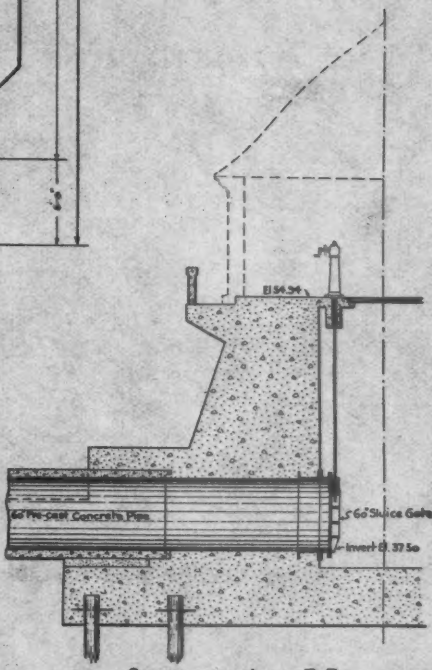
SECTION ON LINE A-A



HORIZONTAL SECTION THROUGH PORTS



ELEVATION



SECTION ON LINE B-B

NEW BEDFORD WATER BOARD

ADDITIONAL LITTLE QUITTACAS INTAKE

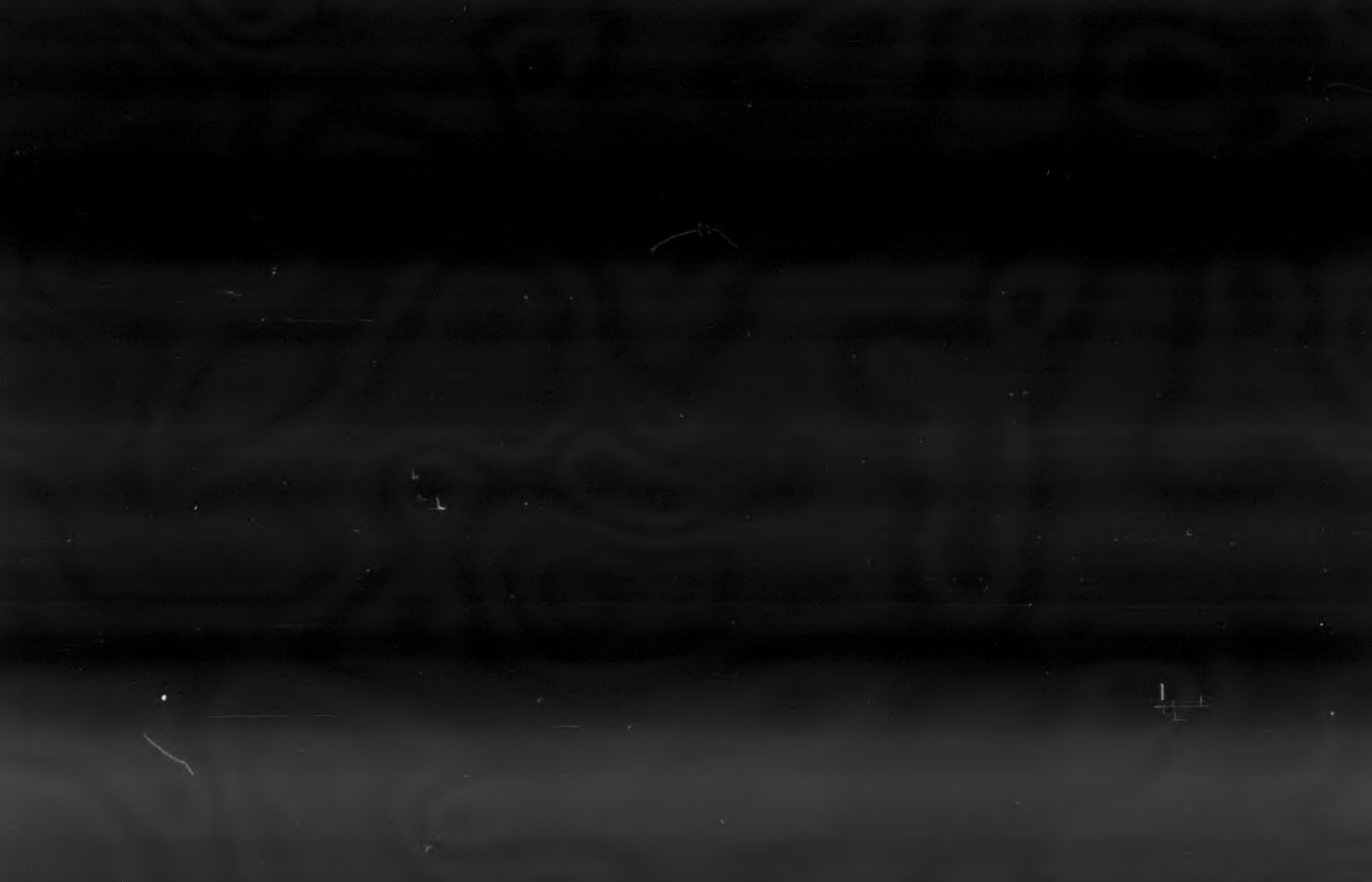
INTAKE TOWER SUBSTRUCTURE

Scale in Feet

March, 1925.

Stephen H. Taylor
Supt of Water Works

Barbour and Dixon,
Engineers



at 5 cents per kw. hr. equals 7.5 cents per hour. The water discharged by the two lines of 2-in. spray pipes, perforated with $\frac{1}{8}$-in. holes, $\frac{5}{8}$ in. on centers, depends of course on the pressure. At 20 lbs., the discharge is 100 gal. per minute, and from experience to date, this would appear to be a sufficient amount and velocity to effectively clean the screen. Figuring $15 per million gal., — the approximate expense of pumping, — the cost of the water used on the screen equals 9 cents per hr., making the total cost of operation somewhat less than 20 cents per hr. As under ordinary conditions of the pond it is not necessary to run the screen for more than a few revolutions at considerable intervals, the actual cost of operation is negligible.

The screen can be started either from a switch in the screen house or from the pumping station. Provision was made for applying steam to the screen in case of clogging by anchor ice, by laying an insulated pipe in conduit from the pumping station.

Intake Tower Design.

The intake tower provides the necessary inlet openings for the admission of water from the pond and the location for a sluice gate by which to shut off the water from the conduit.

The outstanding force to be considered in the design is ice thrust; wind action is a minor factor; adequate weight or anchorage to counteract sliding and overturning are the essential requirements.

The vertical projection exposed to ice thrust is, therefore, made as small as will provide the horizontal section necessary for an area of ports sufficient to reduce the inlet velocity of the water to a reasonable minimum. The lower this velocity, the less the tendency to draw in floating material. Hering, Benzenberg & FitzGerald at Cleveland recommended that the inlet velocity be reduced to 3 or 4 in. per second.

The intake substructure at New Bedford (see Plate V) consists of an octagonal bottom slab of reinforced concrete, 42 ft. in width between parallel faces, and 5 ft. thick, surmounted by an octagonal reinforced concrete tower 30 ft. in width between parallel faces at the top of foundation slab and decreasing to a width of 21 ft. 6 in. at the elevation of high water by a batter of one horizontal to three vertical on the walls. The distance between the parallel faces of the octagonal interior of the tower is 12 ft., and the thickness of the walls varies from 9 ft. at the junction with the foundation slab to 5 ft. at the water line.

The foundation slab is sunk its full depth into the sand bottom of the pond, and for additional support and anchorage, 48 oak piles (see Fig. 3), 12 in. in diameter at the point of cut-off, were required to be driven 30 ft. below the bottom of the slab — the piles projecting 24 in. into the slab and being tied thereto by $1\frac{1}{2}$-in. steel pins 36 in. long, passing through holes bored in the piles 1 ft. below the top and over the lower network of the steel reinforcement of slab.

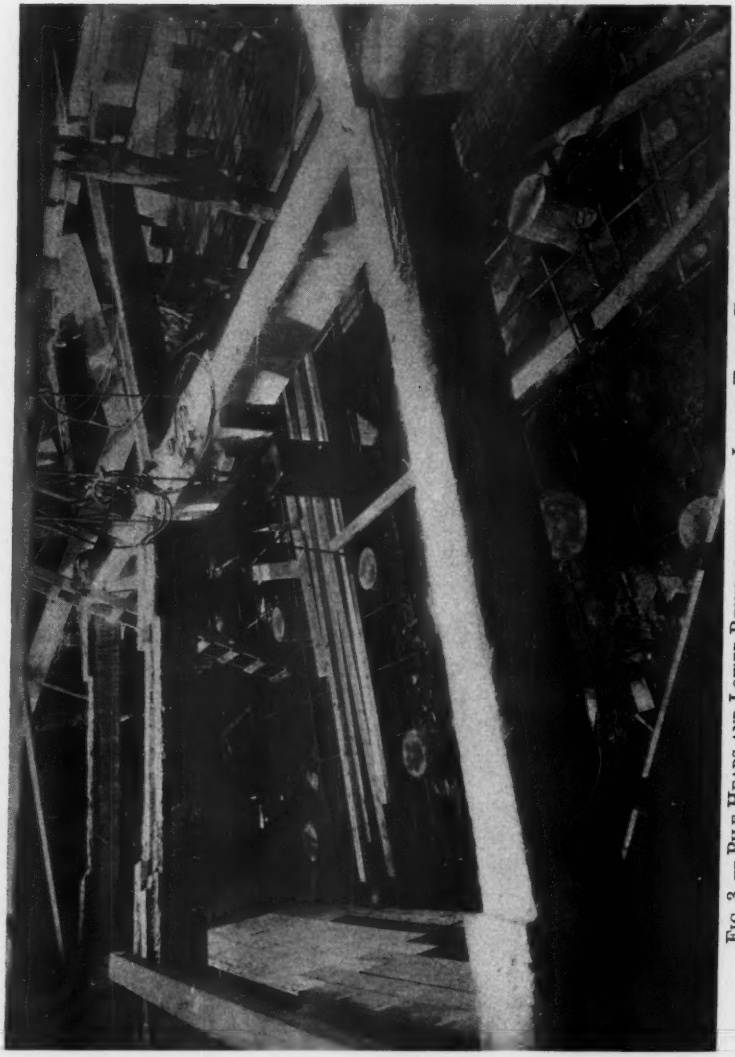


FIG. 3. — PILE HEADS AND LOWER REINFORCEMENT OF INTAKE TOWER FOUNDATION SLAB.

The design is based on an assumed ice thrust of 22 500 lbs. per ft. of width of the projection of the tower at a level 6 in. below full pond and applied at this elevation, together with a wind load of 20 lbs. per sq. ft. of projected area of tower and superstructure above water level, and 10 lbs. per sq. ft. of projected area of roof, and the providing of such weight and distribution of concrete in the tower and foundation slab that the resultant falls within the middle third and, therefore, with no development of uplift at the heel.

In the opinion of the writer, the assumed ice thrust is greater than will ever come against the tower. The assumption of this or of greater pressure disregards the failure of the ice sheet as a long column and the inability of the shores to provide the abutment necessary for the reaction of any such thrusts.

No allowance was made for the depression of the foundation slab 5 ft. into the hard, compact sand bottom, nor for the horizontally slanting surfaces and vertical batter of the tower, nor for the anchorage against uplift of the foundation slab to the pile heads; all of which conditions remain as additional factors of safety, and — if given reasonable values — indicate the tower to be stable against an ice pressure of double the intensity of that primarily assumed.

To provide a low inlet velocity, ports 5.0 ft. by 3.5 ft. at the outer end and reducing to 2.5 ft. by 2.5 ft. at the interior wall face, were placed in six of the octagonal faces of the tower. The total port area at the point of entrance from pond is, therefore, 105 sq. ft., or $5\frac{1}{3}$ times the area of the conduit, and the inlet velocity is $4\frac{1}{2}$ in. per second when drafting at the rate of 25 million gal. per day. The bottom of the ports is 3.5 ft. above the bottom of the pond, and the top at the minimum probable water level of the pond. Provision is made for closing the ports by stop planks — thus rendering the interior of the tower accessible for inspection without emptying the conduit line.

Eighteen inches above maximum water level in the pond, the tower is corbelled out to form a platform around the superstructure, and finished by a concrete and pipe railing. The superstructure is faced with random-coursed ashlar granite, lined with brick and roofed with red slate. (See Fig. 7.)

Contract Prices.

Four bids were received on October 5, 1923, for construction of the intake, and as prices for this class of work are not frequently available, the figures submitted may be worthy of record. (See Table 1.)

The totals of the preceding bids are as follows:

	Based on pre-cast pipe.	Based on poured-in-place conduit.
Contractor No. 1	$153 655	$212 313
Contractor No. 2	159 748	163 314
Contractor No. 3	170 004	175 996
Contractor No. 4	186 390	198 050

TABLE 1.

CANVASS OF BIDS OPENED OCTOBER 5, 1923.

CONSTRUCTION OF ADDITIONAL LITTLE QUITTACAS INTAKE CONDUIT.

Item No.	Description.	Quantity.	Prices Bid.			
			Contractor No. 1.* Unit Price.	Contractor No. 2. Unit Price.	Contractor No. 3. Unit Price.	Contractor No. 4. Unit Price.
	SECTION A (Pumping Station to Screen Chamber).					
1-A	Earth excavation above elev. 45.0	400 cu. yd.	$11.20	$5.95	$4.00	$5.00
2-A	Earth excavation below elev. 45.0	240 cu. yd.	11.20	15.30	6.00	10.00
3-A	Rock excavation	60 cu. yd.	39.40	20.00	24.00	20.00
4-A	Laying 60 in. precast concrete pipe	80 lin. ft.	6.00	16.40	17.00	90.00
5-A	Building 60 in. concrete conduit in place	90 lin. ft.	64.00	39.10	50.00	100.00
	SECTION B (Screen Chamber to Intake Tower.)					
1-B	Earth excavation for screen chamber above elev. 45.0	100 cu. yd.	$7.05	$5.10	$6.50	$5.00
2-B	Earth excavation for screen chamber below elev. 45.0	280 cu. yd.	7.05	11.10	7.50	10.00
3-B	Earth excavation for intake tower	320 cu. yd.	17.40	12.40	13.50	5.00
4-B	Dredging around intake tower	300 cu. yd.	12.95	2.30	20.00	5.00
5-B	Rock excavation	80 cu. yd.	39.40	22.00	25.00	20.00
6-B	†Laying 60 in. precast pipe	1 155 lin. ft.	83.50	84.30	79.25	113.00
7-B	Building 60 in. concrete conduit in place	1 175 lin. ft.	132.00	85.90	83.00	121.00
8-B	Concrete masonry in screen chamber and intake tower	800 cu. yd.	19.70	23.00	27.20	20.00
9-B	Portland cement used in screen chamber and intake tower substructure	1 200 bbls.	4.55	5.00	3.75	3.25
10-B	Reinforcing steel	23 000 lbs.	0.10$^{9}/_{10}$	0.08	0.06	0.05
11-B	Intake tower foundation piles	1 700 lin. ft.	1.26	.88	1.10	1.25
12-B	Screen chamber superstructure	lump sum	5 500.00	9 800.00	14 516.00	7 200.00
13-B	Intake tower superstructure	lump sum	3 700.00	8 000.00	13 200.00	11 000.00
14-B	Retaining wall masonry	150 cu. yd.	28.40	25.80	26.50	30.00
15-B	For furnishing and placing miscellaneous iron work, wood floor grills, etc., and for placing gates, furnished by city	lump sum	2 600.00	2 940.00	2 200.00	2 000.00

* Successful bidder.

† Pipe furnished by city.

On October 5 a bid was also received for furnishing 60-in. precast pipe from the Lock Joint Pipe Company, the total equalling $23 372, which, if added to the total of the preceding bids, based on use of precast pipe, results in the following comparative totals:

	Based on precast pipe.	Based on poured-in-place conduit.
Contractor No. 1	$187 040	$227 605
Contractor No. 2	191 685	174 085
Contractor No. 3	199 217	184 976
Contractor No. 4	222 562	212 650

As already stated, it was concluded to use precast pipe, and the work was awarded to Contractor No. 1, the R. H. Beattie Company of Fall River, the lowest bidder on this type of conduit. In the opinion of the writer, this decision was fully justified by later experience in doing the work.

The contract was awarded for both Sections A and B, the Water Board having decided not to undertake with its own employees the building of the inshore section.

Construction Notes.

The inshore section between pumping station and screen house developed nothing of general interest. The bottom was of a clayey sand, with some ledge, and except for a few feet adjacent to the station where the steel sheeting had to be driven 7.0 ft. below grade, there was no evidence of the difficult foundation conditions reputed to have been encountered in the building of the station.

The connection of the conduit with the old pump well involved cutting through a 54-in. granite rubble wall, which is a monument to the standard of workmanship maintained by Rice & Evans, eleven days being required to break out the opening. As a preliminary step to the cutting of this wall, the pump well was divided by a wooden bulkhead, so as to permit continuous pumping from the other end of the well of the supply furnished through the old conduit.

The general scheme of the contractor for the handling of the offshore section of the work was based on the construction of a temporary pile trestle carrying a standard gage track, over which all material might be transported from a point on shore to its necessary place in the work, and from which the driving and pulling of steel sheeting, the removal and replacement of excavated material and the laying of the pipe might be done by derrick and crane.

The concrete mixing plant was located on shore near the screen chamber, and at this point, from which the track running over the trestle started, a stiff-legged derrick was erected.

The trestle was constructed of bents — on 8-ft. centers — of three piles, capped by 8-in. x 12-in. cross timbers which supported two 12-in. x 12-in. and three 6-in. x 12-in. stringers, on which were laid 4-in. x 10-in. ties,

16 ft. long. The nearest pile in the trestle bents was placed 18 ft. from the center line of conduit; the rails were laid on the side of the trestle toward the trench, and the remaining space on trestle used for storage and for passing by the derrick and crane. The oak piles, which were generally 12 in. in diameter at the butt, were driven by a steam hammer.

A pile-driver frame, rigged with a boom and skidded along the trestle, was largely used in placing the steel sheeting and in suspending the No. 5 Union steam hammer used in driving the sheeting. The characteristics of this hammer were: weight 1 400 lbs., weight of ram 214 lbs., bore $4\frac{1}{4}$ in., stroke 9 in., speed 200 blows per minute, steam pressure at boiler 80 lbs. The moving of material, including sheet piling, concrete, and pipe from the shore to the work, and of handling the excavated material, was done by a 30-ton Ohio steam-driven locomotive crane, with rotary upper frame, mounted on 8-wheel truck. This machine served as a hoisting-engine, swing derrick, and switcher, and also as a means of testing the shock-resisting quality of the precast pipe and the patience and courage of the contractor. Twice, through carelessness on the part of the operator, it was tipped over — the second time landing on one of the pipe sections, chipping the end concrete and bending the end ring, but without crushing the pipe length. These two accidents, one of which was due to operating the machine without sufficient counterbalance, and the other to running on a curve and swinging a load on the inside at the same time, resulted in substantial losses to the contractor, both in the cost of the necessary repairs and in the delay and disorganization of the work.

As required by the contract, the pond was kept down approximately to Elev. 44.5 during the building of the intake, or at an elevation 7.5 ft. above the bottom of conduit and 12.0 ft. above the bottom of the foundation slab of intake tower. The depth of the conduit trench gradually reduced from 12.0 ft. at the shore of pond adjacent to the screen chamber to 1.5 ft. at the junction with the intake tower — the depression of the pipe below pond bottom at the shore line being therefore adequate to protect the pipe against ice thrusts.

Beyond the screen house, the trench was supported and the water — except such as seeped through the bottom — was excluded by Lackawanna straight-web type, 40 lbs. per ft., steel sheeting, 24 ft. long, and driven from 7 to 12 ft. below the bottom of the conduit.

Up to a point 160 ft. beyond the screen house, relatively little water and few difficulties were encountered; at this point, the first cross bulkhead of steel sheeting became necessary. From there on, the general method of handling the work involved the following routine: 1st, the driving in advance of the sheeting necessary to enclose a 72-ft. length of trench (see Fig. 4); 2d, the moving ahead of the pumps and the unwatering of the advance sheeted section; 3d, the excavation of the trench and the removal of the last preceding bulkhead of steel sheeting; 4th, the filling in with screened gravel of the pump well of the last section, the driving of a cross

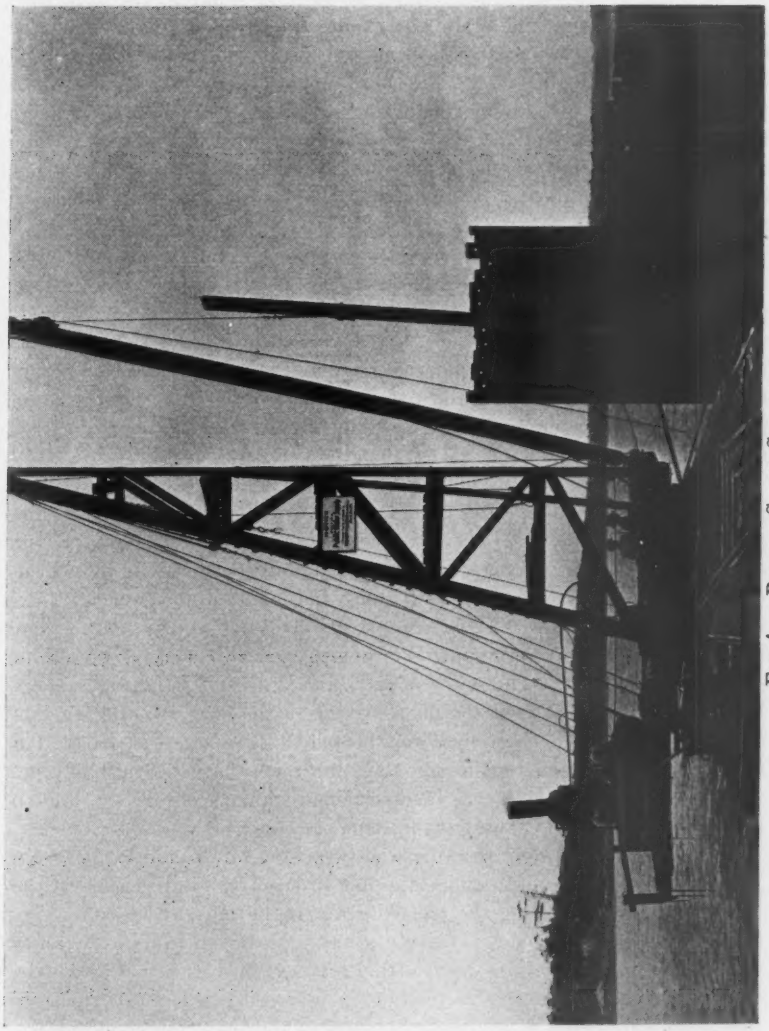


FIG. 4. — PLACING STEEL SHEETING.

line of wooden sheeting about 4.0 ft. back of the outboard steel bulkhead to form a new pump well, and also of another transverse double line of 2-in. x 6-in. hard pine sheeting, 4 to 6 ft. below grade, about 4 ft. back of the pump well sheeting to discount undermining of the pipe foundations; 5th, the laying of a line of 6-in. tile drain, surrounded by screened gravel on either side of the trench close to the sheeting and leading to the forward pump well, and the placing of 4-in. x 12-in. hard pine sills across the trench, 4 ft. apart (see photo); 6th, the placing of the pipe on the cross sills, the pulling together of the pipe sections by tie bolts working between eye bars set on either side of the pipe in the sockets provided for this purpose; 7th, the setting up of panel forms for the loading concrete and the placing of this concrete.

Four (4) ft. back of the bell end of last pipe laid, and directly over the wooden sheet piling cut-off already described, a bulkhead of concrete was poured under and around the pipe, across the full width of the trench, and up to a level 6 in. above the water in the pond, thus closing the trench of the section last laid, shutting out the pond, and permitting the backfilling to be placed within the sheeting not yet pulled. The underdrains were plugged at this concrete bulkhead, thus limiting the water to be pumped at any time to that seeping into a 72-ft. length of trench.

Coincidently with the work of excavating and pipe-laying, another gang was engaged in pulling sheeting from the next to last preceding section and in driving it ahead in an advanced 72-ft. section — the first step in extending the sheeting being the floating into position and lining by transit of three timber frames — each 24 ft. long and made up of 12-in. x 12-in. rangers and three 10-in. x 12-in. cross struts, held in place by bolting to a 4-in. x 10-in. timber overlapping the rangers. This frame, placed at the elevation of water in pond, was the only bracing used — no lower rangers being necessary because of the deep driving of the steel sheeting and its capacity as a beam. The trench was sheeted 12 ft. wide; the space of 10.5 ft. between cross bracing made easy the lowering of the 8-ft. length of pipe.

The bottom material was compact sand, ranging from very fine to moderately coarse, and containing in some places considerable silt and clay. The tightness of the steel sheeting was surprising, after cinders had been sifted into the joints and outside the line of sheeting, and in general the amount of water entering the trench through the bottom was relatively small — two 4-in. pulsometers being at times sufficient to remove the inflow after the original pumping-down of a 72-ft. section. In other locations, varying with the coarseness of the bottom material, the leakage was sufficient to require two 6-in. centrifugal pumps, in addition to the pulsometers. Where the material was coarse and the water came through freely, there was no tendency to uplift of the bottom. The dangerous condition was where the material was fine and compact and the amount of seepage small, when the unbalanced pressure on the bottom caused boils and uplift and at several points required loading of the trench with gravel.

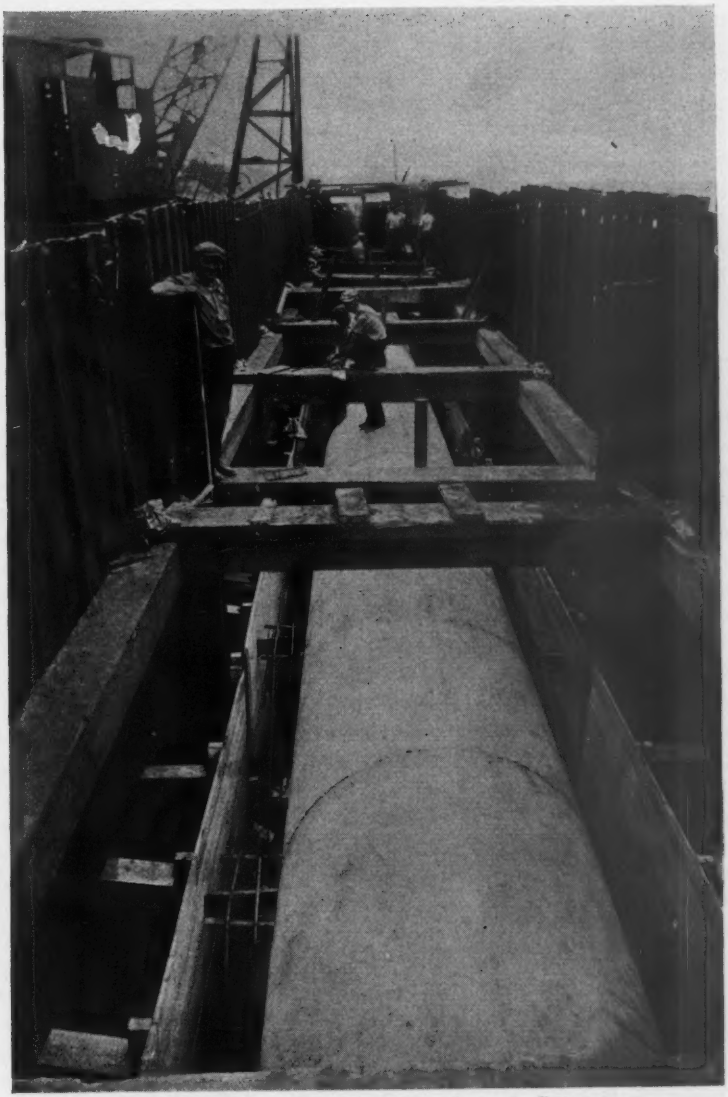


FIG. 5. — PIPE READY FOR PLACING OF LOADING CONCRETE.

The permitting of a pump well at 72-ft. intervals, excavated 3 to 4 ft. deep below the grade of the conduit and extending across the width of the trench, was a concession to the difficulty of otherwise providing the necessary sumps. At the first pump well beyond the screen house, undermining of the concrete pipe occurred, but after starting the wooden sheet pile cutoffs, no further serious trouble developed, and no subsequent settlement has resulted, so far as is known, at the points where the pump wells were located.

For about 300 ft. beyond the screen chamber, the amount of water encountered was so small that no underdrain was necessary, the seepage being carried to the pump well by shallow ditches adjacent to the sheeting. At about station 4 + 0 the inflow became greater and the laying of a 6-in. underdrain, surrounded by 12 in. of screened gravel, on both sides of the trench adjacent to sheeting, was begun, and continued thereafter. At about this point, also, because of the quaking character of the bottom, the contractor began placing the two 4-in. x 12-in. cross sills as a precaution against settlement. At Sta. 4 + 75, because of insufficient depth of sheeting, the bottom blew up, necessitating careful refilling with gravel and the driving of the steel sheeting 12.0 ft. below grade. As already stated, such trouble as was encountered in controlling the bottom was due to fine material which dammed back the water and necessitated loading with screened gravel to prevent blowing up. It was under such conditions that the value of the precast pipe, in reducing the time during which the dangerous trench bottoms had to be kept open, was most apparent. At certain points it would have been impossible, or at least extremely difficult, to build a satisfactory poured-in-place conduit.

The 8-ft. lengths of 60-in. pipe were picked up on shore and carried to the trench by the locomotive crane. The joints were painted with graphite, the lead gasket tapped into place in the bell end of the preceding section, the pipe lowered to place and drawn home by the tie bolts, or in some cases by a tackle anchored to a timber wedged diametrically across the preceding section. After pulling the joints together, the gasket was pushed into the wedge-shaped opening formed by the bell and spigot rings until the edge of the gasket was flush with the outside of the spigot ring. The outside of the joint was filled with 1-1 mortar and after several pipes had been laid ahead and the loading concrete placed, the inside joint was finally calked by driving the gasket firmly to place and the joint recess filled with mortar and rubbed flush and smooth by carborundum blocks. Two men were constantly engaged in doing the final calking, filling and smoothing of the interior joints when the progress of pipe-laying equalled 72 ft. per week. The joints when properly finished are hard to find, and the interior of the conduit is a clean, smooth wall of concrete which should develop a very low frictional coefficient. No opportunity for observation of the leakage into the conduit after the pond refilled to full elevation has occurred, but no seepage was in evidence under a head of 6.0 ft. on the center of the pipe at the last inspection.

FIG. 6. — CROSS SILLS; PRECEDING CONCRETE BULKHEAD, AND GASKET IN JOINT READY FOR NEXT SECTION.

The first step in the construction of the intake tower was the extension of the trestle on a curve of 300 ft. radius to a terminus at the center of the tower. A frame of 12-in. x 12-in. timber, 46 ft. square, was built on shore and floated to position to serve as the top bracing of the cofferdam. The steel sheeting was driven 15.3 ft. deep into the pond bottom, or 10 ft. below the under side of concrete foundation slab, the 184 feet of peripheral length of sheeting being driven in twelve 8-hr. shifts. The cofferdam was unwatered in 4 hrs. by two 6-in. centrifugal pumps and three 4-in. pulsometers, and after the sheeting had been calked by cinders, only a small quantity of water entered through the bottom, which was of fine sand containing some silt and clay — a condition which, as had been evidenced by earlier experience, was more dangerous than if the material had been coarse and such as would permit a uniform and well-distributed inflow.

Having excavated the bottom to within 6 in. of grade, the water was allowed to rise slightly in order to reduce the unbalanced pressure before beginning the driving of the foundation piles, which was done by a McKiernan-Terry No. 7 double-acting steam hammer, total weight 5 000 lbs., bore 12½ in., stroke 9½ in., speed 225 blows per minute, steam pressure at boiler 80 lbs.

The pile layout followed the octagonal plan of the tower, with an outside row on 4.0-ft. centers and 2.0 ft. inside of the face of foundation slab and an inside row on 5-ft. 6-in. centers and 7 ft. 6 in. from face of slab. Every pile drove hard throughout its length — the average rate of sinking being 2.0 in. per minute and the penetration during the last minute generally less than ½ in. The underlying material, as evidenced by preliminary wash borings and as indicated by the pile-driving, is a compact dead sand. One interesting condition incident to the pile-driving was the immediate increase in leakage through the steel sheeting and the bottom, due to the resulting tremors.

The piles having been driven, the water was again lowered and pump wells sheeted and excavated in two corners of the cofferdam square outside the limits of the octagonal concrete slab. From these pump wells, lines of 8-in. vitrified clay pipe, surrounded by screened gravel, were laid around the entire periphery of the cofferdam. In the meantime, springs had been forming in the bottom, and in the night of September 7th, the water broke through, flooding the cofferdam and forming a hole 8 ft. deep and of considerable area. This hole was filled with selected gravel and the pond bottom outside of the point in the cofferdam where the break occurred loaded with gravel well heaped up against the sheeting. On September 11 the cofferdam was again pumped out, and thereafter the underdrains and pump well handled the inflowing water without further mishap.

With the leakage under control, the bottom was finally graded and consolidated. the lower network of the foundation slab reinforcement set, and the placing of concrete begun, the bottom slab being poured continuously by working two gangs in 12-hr. shifts. After the concrete had set,

the water was allowed to rise to Elev. 37, the space between concrete and sheet piling carefully backfilled, and the lower set of bracing removed.

The next step was the laying of the final length of the 60-in. conduit which lapped on to the concrete slab and the setting in place of the barrel form for the distance remaining from the end of the precast pipe to the interior face of the tower.

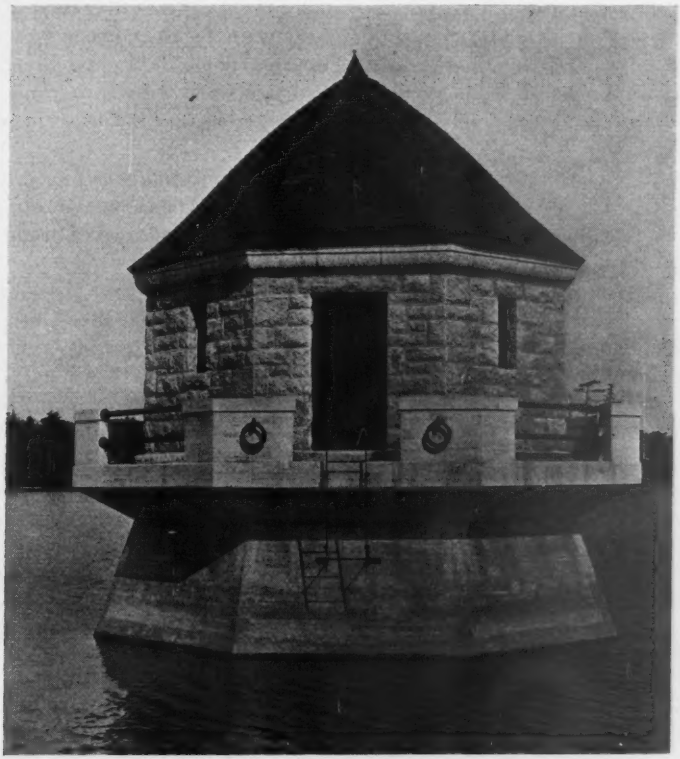


FIG. 7. — INTAKE TOWER SUPERSTRUCTURE.

The first operation in forming the section of the tower above the foundation slab was the fixing of the vertical central axis by a wooden framework 18 ft. high, from which jigs for the inside and outside faces of the tower were suspended. The wall forms were then studded and lagged in place, the port forms, which had been made on shore, set in position, the concrete poured to Elev. 45, where it was stopped — in order that the tower at this elevation might serve as a support for the track and crane in doing the dredging and in pulling the sheeting. With the concrete thus placed to a height approximately one foot above the then elevation of the pond, the

forms were removed, the port openings closed by stop planks, and the water allowed to rise in the cofferdam, thus saving the expense of further pumping.

The objective of the dredging was to remove for a radius of 70 ft. around the intake tower the relatively thin layer of soft mud which overlay the sand. The work was done by the crane with a 15-ft. extension on the boom and a steel plate scraper suspended from the main cable — the scraper being thrown out to the maximum required radius by a combination of the swing of the cable and the operation of the crane boom and then drawn in close to the cofferdam, where its load of mud was deposited and subsequently removed by clamshell bucket and carried to shore. Very little sand was disturbed and three complete circuits effectively cleaned the adjacent pond bottom.

After finishing the dredging, the cofferdam sheeting was pulled, generally by a steady, hard strain from the crane and coincident vibrating of the piles by blows from a heavy hammer, but in some cases by using the steam pile-driver, rigged upside down.

The forms for the remaining lift of the substructure were then placed and the concrete poured, after which the dismantling of the floor system of trestle was begun, the material for the superstructure having been first stored on a platform at the outer end of the trestle.

The contract required that the work should be completed on or before October 1, 1924, but owing to various causes, the intake superstructure was not begun until November 11, and the officials of the city were very properly insisting that the pond could no longer be kept down to minimum elevation, but should be allowed to refill. It therefore became necessary to remove the floor system of the trestle at the earliest possible date, and in the final stages of completing the intake superstructure, the workmen were transported to and fro by boat, with more or less interference by ice. The trestle piles were allowed to remain in place — the tops being at Elev. 44.0 or below probable minimum level of pond.

Cost of the Completed Work.

The cost of the completed work — including the construction contract, the pipe, screen, and other material furnished by the city, and the engineering and inspection — was $206 773, and, remarkable to relate, this was $3 227 less than the estimated cost submitted by Mr. Taylor and the writer in a preliminary joint report made to the Water Board. However, as may well be suspected in work of the character described, it cannot be claimed that the various items making up the total were in similar accord. The contractor's records show a loss on the job of about $20 000, and this is approximately checked by the cost account kept by Mr. Elson T. Killam, resident engineer for the writer's firm, and now assistant superintendent of the New Bedford Department. This loss is in great part explained by the small salvage in steel sheeting and trestle timber, by the expense and

disorganization resulting from accidents to equipment and, particularly, by the always uneconomical night work undertaken in trying to complete the contract within the specified time.

The superstructure was designed by Mr. Charles M. Baker, architect, whose services were enlisted by the writer's firm.

The major part of whatever credit accrues from the work herein described is due your honored past president, Stephen H. Taylor, Superintendent of the New Bedford Water Department, and only his extreme modesty has furnished excuse for the writer to undertake the authorship of this paper.

THE NEW SEBAGO LAKE INTAKE AND CONDUIT OF THE PORTLAND WATER DISTRICT.

BY LEONARD METCALF,* HARRY U. FULLER,† AND CHARLES B. MITCHELL.‡

[*Read November 10, 1925.*]

Probably the most interesting work of its kind ever attempted in the State of Maine has just been completed at Sebago Lake by the Portland Water District. This is the construction of a new intake and conduit for increasing the water supply of the city of Portland and surrounding towns, serving a population of about 105 000.

In February, 1867, a charter was granted to the Portland Water Company, authorizing it to take water from Sebago Lake. Four hundred and eighty feet of 48-in. cast-iron pipe, laid into the lake, brought the water to a gate and screen house. From this point 5 470 ft. of conduit were built through the native rock, lined with brick except for a distance of about 671 ft. in tunnel, and improved in 1880–1884.

This conduit was built largely in open cut, of sections of four general types, varying in width from 3 ft. to 4 ft. 6 in., and in height from 4 ft. 6 in. to 7 ft. Unfortunately, in its construction a bad hump or high section was left in the floor of the conduit, extending over a distance of between 1 500 and 2 000 ft. projecting above the normal plane of the floor 18 in., more or less. This hump decreased the available cross-section and increased the loss in head in the conduit and seriously reduced the carrying capacity of the tunnel, and the available storage in the Sebago "Basin," hereafter referred to, particularly at times of low water in the lake.

From the end of the conduit a cement-lined wrought-iron pipe 20 in. in diameter carried the water to the city, 16 miles distant.

In 1876 a new wrought-iron cement-lined pipe, 26 in. in diameter, was built from the terminus of the conduit to Ward's Hill, a distance of about four miles; and in 1902 a 30-in. cast-iron main paralleling it, greatly improving the service.

To ameliorate the conditions created by the hump in the conduit and give greater opportunity for temporary repairs to the conduit in case of need, the Portland Water Company built in the year 1902, under the direction of Percy M. Blake, a reservoir known as the "Basin," at the lower end of the conduit. The conduit and the three mains leading to Ward's Hill, already referred to, were connected to this Basin or reservoir.

In 1877 a new 24-in. wrought-iron cement-lined pipe was laid from Ward's Hill to the city, in extension of the 30-in. and 26-in. mains and

* Of Metcalf & Eddy, Consulting Engineers, Boston, Mass.
† Chief Engineer, Portland Water District.
‡ Resident Engineer, Portland Water District.

paralleling the 20-in. supply main, thus reinforcing the available capacity of the system.

In 1912 a 42-in. cast-iron pipe was laid from the Basin to the city, 17 miles in length.

In 1907 the Portland Water District was created and took over the properties of the Portland Water Company.

The District consists of the city of Portland, exclusive of its islands, and the city of South Portland, — the city of Westbrook declining to become a part of the corporation. The district now served covers a distance of upwards of 20 miles along the seacoast, extending from Falmouth Foreside on the north, through East Deering, Deering Junction, Deering and Portland, to South Portland, Cape Cottage, Cape Elizabeth, Higgins Beach and Prout's Neck; serving also, farther inland on the south, Scarboro, Oak Hill, Dunstan Corner, and West Scarboro, just north of the Saco township line.

Between Sebago Lake and the city of Portland — a distance of about 19 miles — the District serves also the towns of Gorham and Westbrook and the villages of Cumberland Mills and Stroudwater.

Little by little, the distribution pipe system of the District has been extended, to meet the growing demands of service and make available to this district the excellent waters of Sebago Lake.

The "mean water level" of Sebago Lake is at Elev. 266; the "legal low water," below which the power interests may not draw, at Elev. 262.5; the "high water level" at slightly over Elev. 271.4.

It is possible to supply the entire district, excepting only the town of Gorham, with water by gravity.

With growth in demand, and recognition of the danger of interruption of service from time to time by breaks in the old wrought-iron cement-lined pipe, it became evident that an additional supply main would have to be laid from the lake, to supplement the deficient capacity of the old conduit.

Gagings made by Richard A. Hale of Lawrence, under the direction of Allen Hazen, indicated a maximum conduit capacity of bout 9 to 9.5 m.g.d. at legal low-water level in the lake; 13 m.g.d. at Elev. 263.3; and 18 m.g.d. at mean-water level.

Consumption of water in Portland and the surrounding towns had reached a point where the capacity of the old conduit was severely taxed and threatened to prove inadequate during the low water period of the lake. At normal low water the old conduit carried about 11 m.g.d., while the maximum flow to the city reached 16 m.g.d. and the night flow 9 m.g.d., — the fluctuation being taken up by the Basin. It was clear that additional capacity would have to be provided or the consumption be reduced by the general introduction of meters. It was assumed that:

First, a covered masonry reservoir having a capacity of at least 12 m.g. and, preferably, 20 m.g., would be built, or a larger open reservoir, in the reasonably near future;

Second, the system of selling all water by meter would be adopted within a relatively short time; and

Third, the supply pipe system should be built with a future carrying capacity of at least 30 m.g.d.

These considerations, and the minimum section which could advantageously be built in tunnel and the necessity of maintaining low velocity of flow in the intake section to minimize the trouble from fish, determined the capacity of the new conduit.

The economical minimum tunnel section generally lies between 7 ft. and 8 ft. in diameter of excavation, which correspond to lined sections 60 in. and 66 in. in internal diameter. The 60-in. internal diameter of tunnel would deliver 50 m.g.d., at a velocity of slightly less than 4 ft. per second, with a loss in head of about 1 ft. per thousand feet of tunnel; and 75 m.g.d. at 6 ft. per second velocity, with friction loss of 2 ft. per thousand. A masonry-lined conduit 54 in. in internal diameter was estimated to give a discharge of 50 m.g.d., with a loss of 1.6 ft. per thousand, and 75 m.g.d. with a loss of 3.4 ft. per thousand.

The length of the intake from shore to deep water, and trouble experienced at times heretofore from small fish entering the intake and screen house, were also factors, making desirable the keeping of velocities in the intake as low as practicable and through the screens not over 0.5 ft. per second. The latter experience has been described by one of the authors in a paper presented before the American Water Works Association.*

After careful analysis it was concluded to build a lake intake 54 in. in internal diameter, 1 580 ft. long, terminating in a gate and screen house over a vertical shaft descending to a tunnel in rock; a masonry-lined tunnel section 60 in. in internal diameter, 2 100 ft. long, discharging into a 54-in. reinforced concrete conduit 1 900 ft. long, connecting with the existing 42-in. and 30-in. cast-iron supply mains. The plan and profile are shown on Plates I and II and the cross-sections on Plate III.

In view of the character of the old conduit, it was thought wiser to build first a new intake into the lake, of adequate capacity, and as secure as possible from the danger of interruption of service.

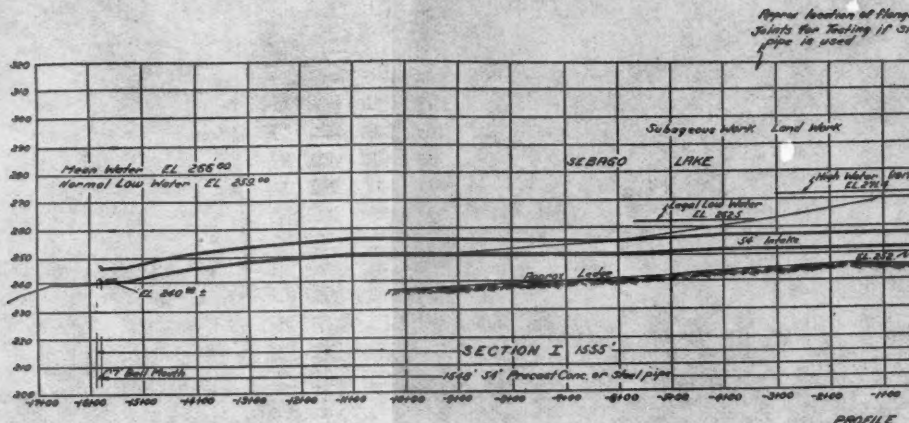
The immediate emergency was cared for by the extension of the power lines of the Cumberland Power & Light Company to the old gate and screen house at the lake, and the installation therein of two centrifugal pumping units of 10 m.g.d. capacity, each driven by a 50 h.p. motor.

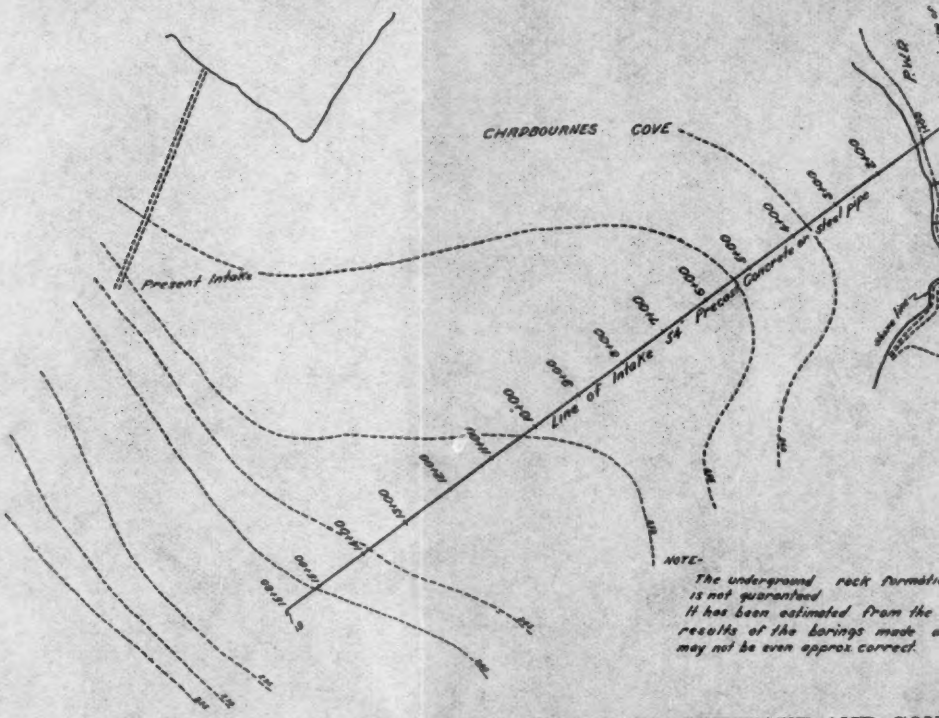
Three methods for the permanent betterment of the service were considered:

First, the deepening and repairing of the old conduit;
Second, the building of a new conduit adjacent to the old one;
Third, the building of a new conduit in a more advantageous location.

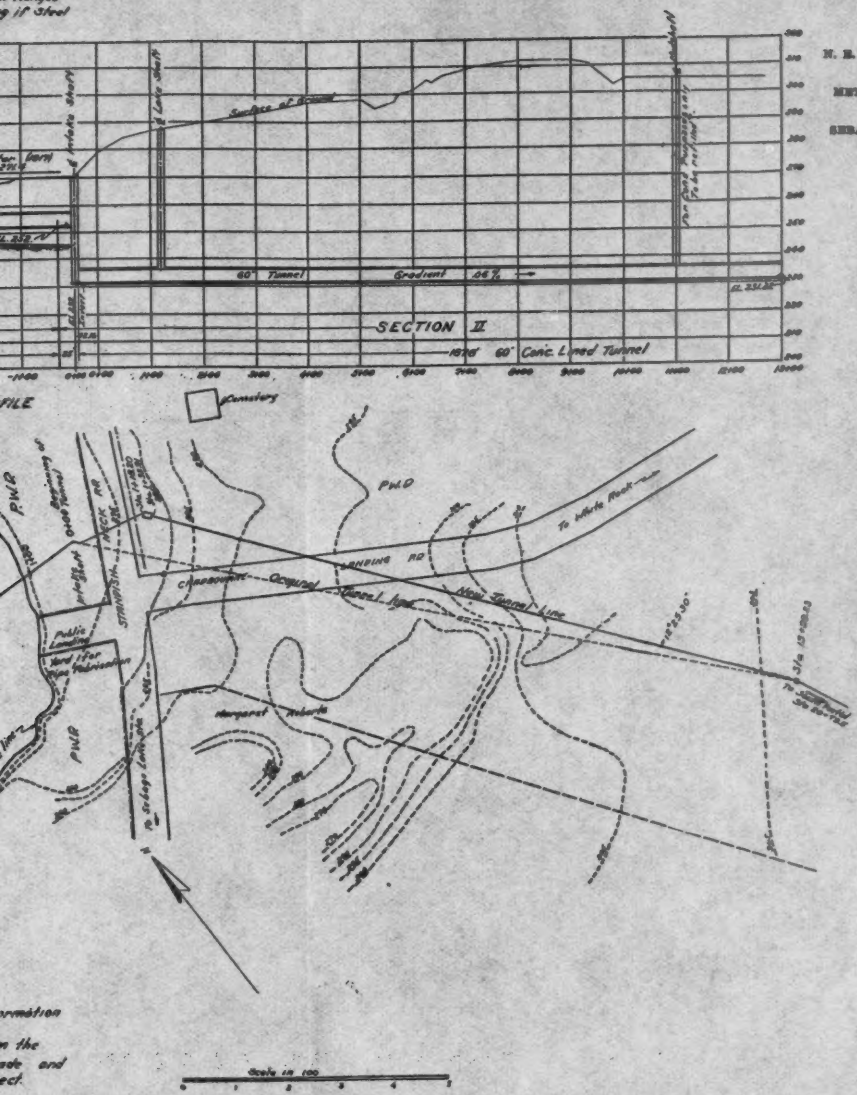
Of the three methods of increasing the intake capacity from the lake to the "Basin" or some point below it, the third, involving the construction

* *Journal*, Vol. x, 1923, pp. 599–602.

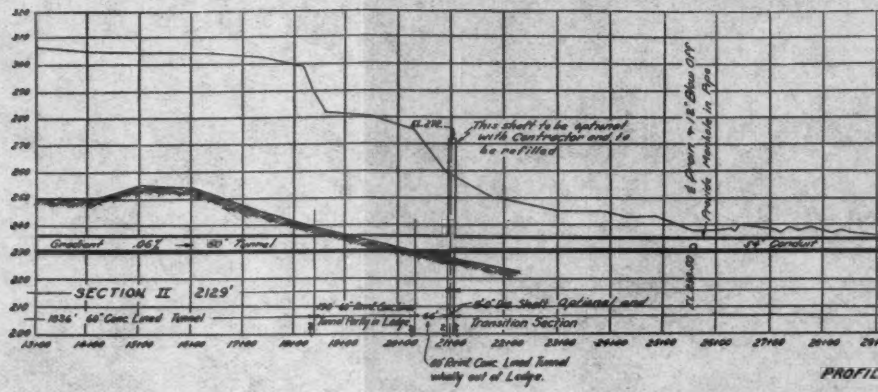


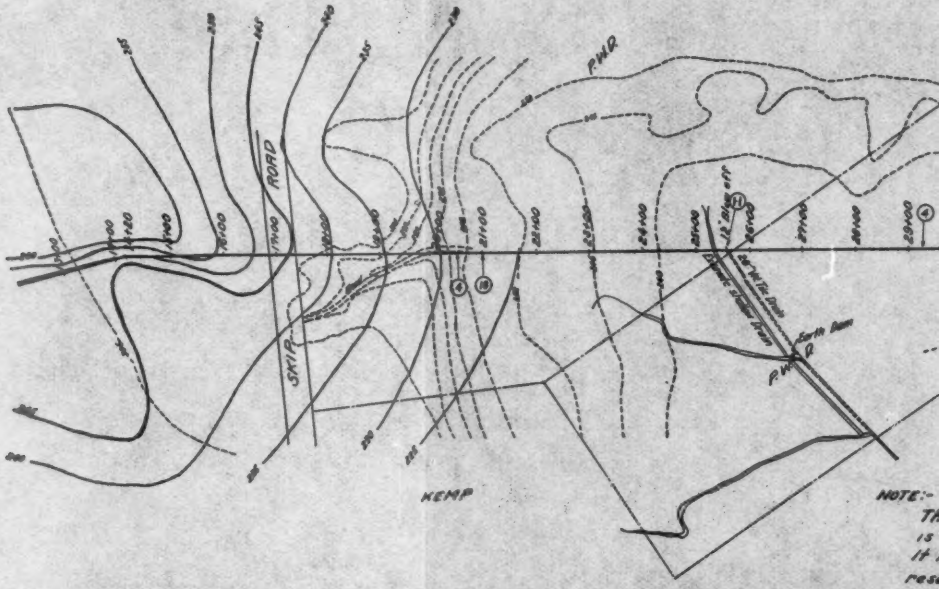

CHADBOURNES COVE
Present Intake
Line of Intake 54" Precast Concrete or Steel pipe
NOTE-
The underground rock formati
is not guaranteed
It has been estimated from the
results of the borings made
may not be even approx correct

SEBAGO LAKE INTAKE AND CON



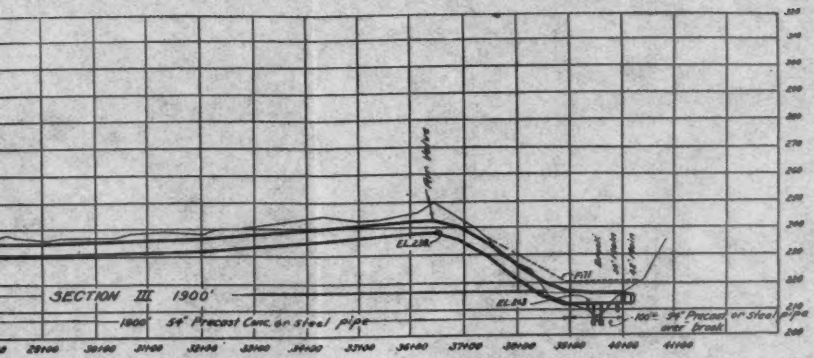
CONDUIT — PLAN AND PROFILE.

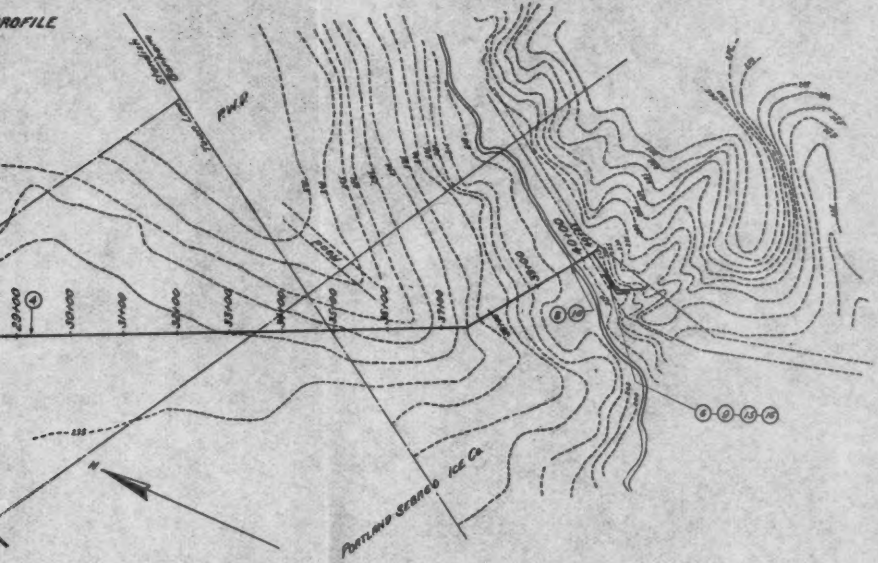

This shaft to be opened with Contractor and to be refilled
Gradient .06% → 60" Tunnel
SECTION II 2129'
1936' 60" Conc. Lined Tunnel
Transition Section
60" Conduit
PROFIL



SEBAGO LAKE INTAKE AND C

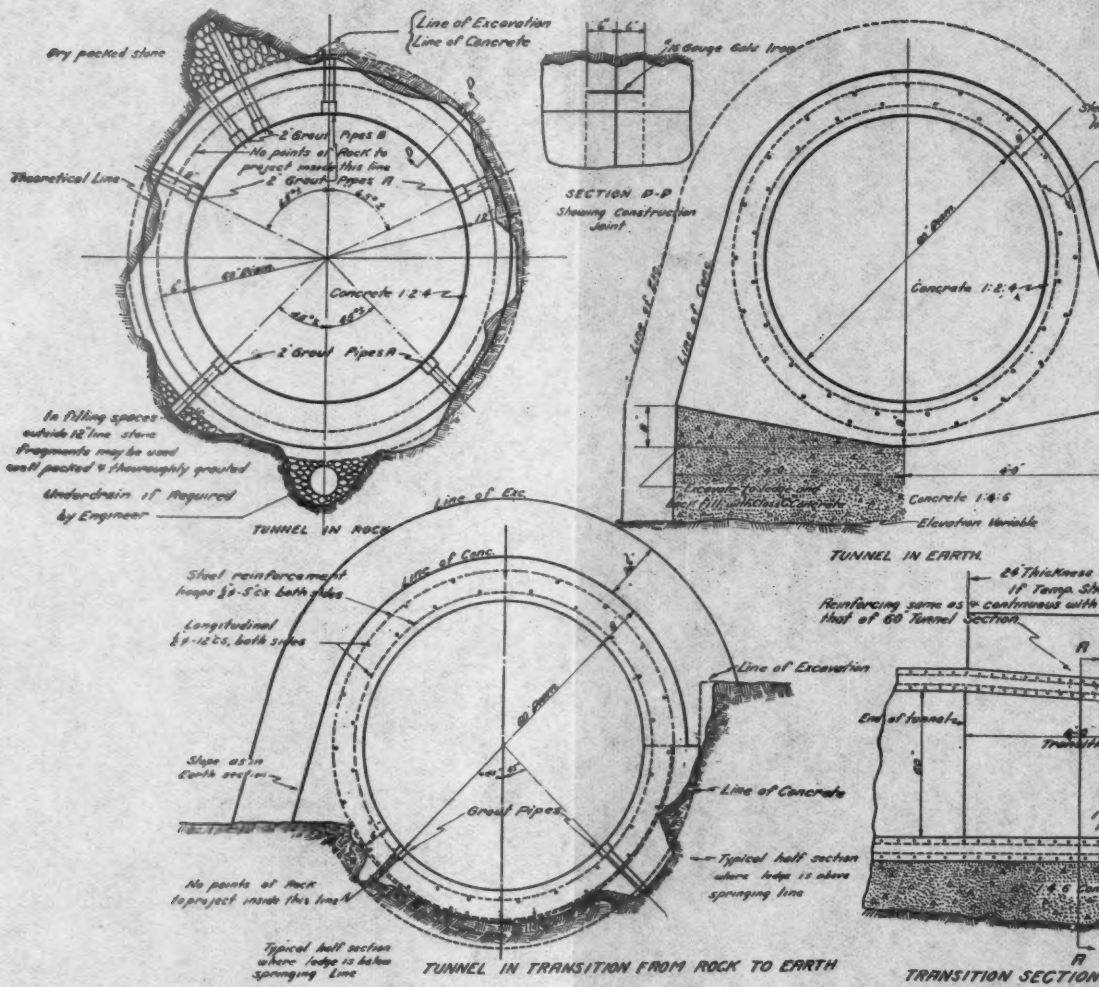
PLATE II.
N. E. W. W. ASSOCIATION.
VOL. XXXIII.
METCALF, FULLER AND
MITCHELL ON
SEBAGO LAKE INTAKE.



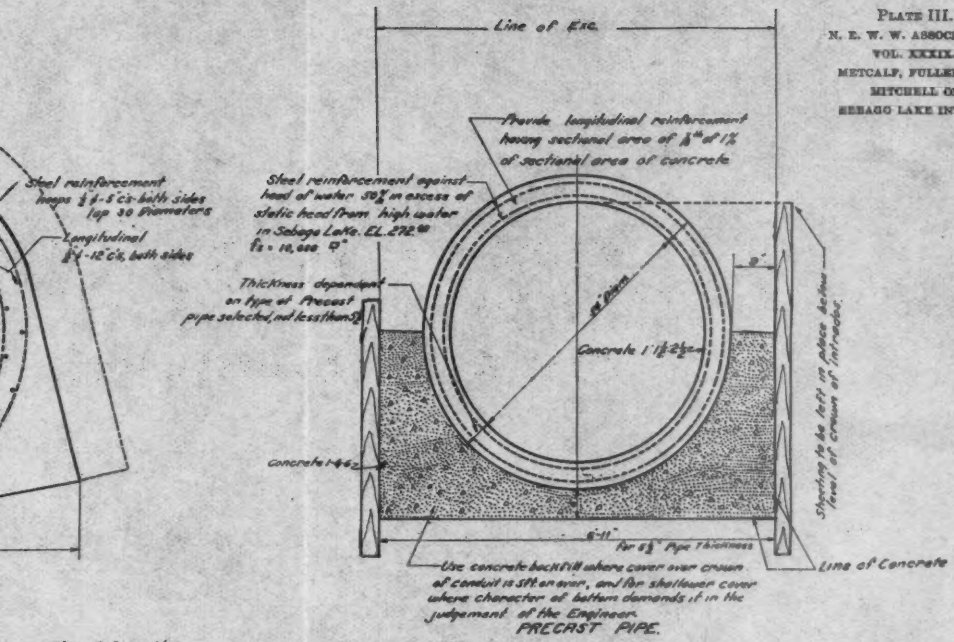


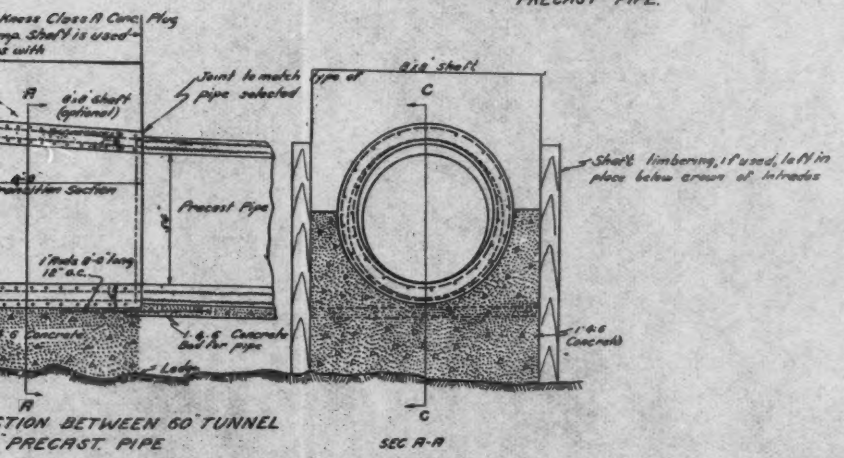
OTE:-
The underground rock formation is not guaranteed. It has been estimated from the results of the borings made.

D CONDUIT — PLAN AND PROFILE.


Spacing of grout pipes A to be standard for entire rock tunnel. Pipes shall be placed, as shown at to be apart, along tunnel. Grout pipes B shall be placed at unusual over-breaks, open seams in rock or elsewhere as directed. Where additional grout pipes are required to fill large voids, they shall be inserted in joints as shown, one to admit grout and the other to permit escape of air and water. Each grout pipe to be provided with coupling and plug at interior face of tunnel lining.
Line of Excavation
Line of Concrete
Dry packed stone
2" Grout Pipes B
No points of rock to project inside this line
2" Grout Pipes A
Theoretical Line
Concrete 1:2:4
In filling spaces outside 12" line stone fragments may be used well packed & thoroughly grouted
Underdrain if Required by Engineer
TUNNEL IN ROCK
SECTION D-D
Showing Construction Joint
Concrete 1:2:4
Concrete 1:4:6
Elevation Variable
TUNNEL IN EARTH
Line of Excavation
Line of Concrete
Steel reinforcement hoops ⅝ @ 5" c.c. both sides
Longitudinal ⅝ @ 12" c.c. both sides
Slope as in Earth section
Grout Pipes
No points of rock to project inside this line
Typical half section where ledge is below springing line
Typical half section where ledge is above springing line
TUNNEL IN TRANSITION FROM ROCK TO EARTH
Reinforcing same as in continuous wall of 60 Tunnel Section
End of tunnel
TRANSITION SECTION
AND 54" PRE
SEC. C-C
Scale

SEBAGO LAKE CONDUIT — TYPIC


Line of Exc.
Provide longitudinal reinforcement having sectional area of 1/8% of 1% of sectional area of concrete
Steel reinforcement hoops 3/4"ϕ-5'c's both sides lap 30 diameters
Longitudinal 3/4"ϕ-12'c's, both sides
Steel reinforcement against head of water 50% in excess of static head from high water in Sebago Lake. EL. 272.00
fs = 16,000 #
Thickness dependent on type of Precast pipe selected, not less than 8"
Concrete 1:1½:2½
Concrete 1:4:8
6'-11"
For 6½" Pipe Thickness
Shoring to be left in place below level of crown of Intrados.
Line of Concrete
Use concrete backfill where cover over crown of conduit is 5ft or over, and for shallower cover where character of bottom demands it in the judgement of the Engineer.
PRECAST PIPE.


Joint to match pipe selected
6'-0" shaft (optional)
Precast Pipe
1" Rods 6'-0" long 18" o.c.
1:4:8 Concrete Bed for pipe
Ledge
Shaft timbering, if used, left in place below crown of Intrados
1:4:8 Concrete
SECTION BETWEEN 60" TUNNEL & PRECAST PIPE
SEC A-A
SEC C-C
Scale ½"=1'-0"
Note
This section not necessary if permanent shaft is built

TYPICAL CROSS SECTIONS.

of a conduit in a new location, was much the most attractive, because this conduit could be built without danger of interruption of service or injury to existing works; more adequate capacity of intake could be provided, with water drawn from a somewhat greater depth, thus probably bettering its quality and reducing the danger of trouble from ice and accidental pollution; and because the length of the line could be materially shortened, thus tending to reduce cost and to conserve head, while still maintaining the advantage of free outfall for purposes of draining, and cleaning or repairing the conduit at any time in the future.

In the summers of 1921 and 1922 preliminary surveys and test borings were made, in order to determine the best location for the new conduits, and in the following winter plans were prepared and specifications drawn for the proposed works.

Method of Determining Economic Location for New Conduit.

Economy dictated that the tunnel should be built in solid rock, since, if constructed in the superincumbent material, — which varied from a coarse, free sand to a very fine clayey sand, — compressed-air methods of driving would be required, which would involve a cost from two to three times as much as driving in rock. At the same time it was desirable to maintain free drainage of the tunnel by gravity, at its land end, if this could be done without running the risk of inadequate rock cover over the tunnel.

After making surveys the topography of the territory for about one-half of a mile along the lake front was mapped, and a systematic exploration was made by wash-drill borings.

Sixty-seven holes, varying in depth from 10 ft. to 81 ft., involving a total length of 2 873 ft., were drilled, in order to determine the depth of rock and the character of the material traversed. A gang of men was organized by the Water District, for this work, under the direction of its chief engineer, and carried on its work from July 6 to November 22, 1921, and May 10 to December 6, 1922. With the information thus obtained, 8 core-drill borings were made by the District, in order to determine the character of the rock and to give contractors as full information as possible upon which to base their bids. The rock was found to be a micaceous schist, apparently generally hard and sound save for an overlying layer from 1 to 2 ft. in depth of more or less disintegrated rock adjacent to the lake. The indications pointed to the probability of but little trouble from water.

The cost of the 2 873 ft. of wash-drill borings was $3 740, averaging $1.30 per ft.; and of the 71 ft. of core-drill borings $590, or $8.33 per ft.; involving a total cost of $4 330.

At a subsequent period, after the construction work was well under way, nine additional holes were driven near the shore of the lake, by the B. F. Smith Company. These holes varied in depth from 35 ft. to 68 ft.

and comprised a total length of 415 ft. Later the contractor returned and drove two additional holes 53 ft. and 69 ft. 3 in. in depth, respectively.

The cost of this later work was as follows:

150 ft. of core-drill borings at $9.50 per ft.	$1 425.00
264 ft. 4 in. at $7 50 per ft.	1 982.50
2 holes aggregating 113 ft. 3 in. at $9.50 per ft.	1 075.88
	$4 483.38

Horizontal diamond-drill borings were also made by The Osborne Drilling Corporation in the tunnel, at a later date, aggregating four holes about 18 ft. each in depth, at a cost of $1 138.

In spite of the extent of these explorations and the care with which the work was done, the information derived proved somewhat misleading, for in the actual construction of the work the roof cover was found to be substantially less than anticipated and there were found at several points narrow but deep depressions in the rock, which broke the rock cover over the tunnel roof, retarded progress, and increased the cost of the work. Moreover, while it was anticipated that at the shore end of the tunnel a section of 200 ft., more or less, very fine running sand would be encountered, in which compressed-air methods might prove advantageous, it was concluded that the conditions were not serious enough to justify the installation of locks and of a plant for compressing air. This conclusion was reached by all of the contractors — who viewed the work and the information accumulated — as well as by the engineers. Mention is made of this fact at this point merely to indicate the hazard involved in such construction and the desirability of giving, where possible, ample thickness of roof to reduce hazard and the amount of water likely to be encountered in the rock work.

Call for Bids. In the spring of the year 1923 bids were invited upon the proposed work, divided into three sections:

Section I — Lake intake.

Section II — Tunnel.

Section III — Conduit at land end of tunnel.

The bids received were all rejected, as labor and construction costs were tending downward and it was thought that more advantageous terms could be obtained a year later.

Work by District upon Section III, etc.

Meanwhile the District organized a crew of men to cut lumber for the job and clear the conduit section; ditch and drain the swampy land adjacent to the tunnel section, and begin the construction of the conduit at the end of the tunnel section, with a view to draining the hillside above it as far as possible, to reduce the water to be encountered later.

The clearing and draining of the swamp was begun in October (1922).

In September the lumbering operations began. Two hundred thousand ft. of lumber were cut by portable mill at a cost of $19 to $30, averaging about $25 per thousand. Eight hundred cords of wood were also cut (at a cost of about $3.50 per cord), 200 cords of which were subsequently sold.

A trench 700 to 800 ft. long was dug in the swamp, along the line of the brook, from the point of the proposed blow-off in the conduit, as a first step in the drainage of the swamp. The material underneath the muck proved to be very fine-running, slightly clayey sand. At a later date this trench, varying from 0 to 8 ft., and averaging about 6 ft. in depth, was sheeted, and in the fall of 1923 a 20-in. tile drain was laid in it, 500 ft. in length. This drain was laid with open joints covered with strips of burlap and surrounded with gravel.

In June, 1923, a new road was built by the District, to the Venturi meter and chlorination house at the junction of the new with the old lines, and early in September work was begun on a 500-ft. section of the 54-in. reinforced concrete conduit, from the end of the tunnel section to the 20-in. blow-off in the swamp. A travelling derrick, stiff-legged, with 60-ft. boom, with electric-drive, made by the American Hoist and Derrick Company, was bought and erected.

Excavation was begun at the blow-off end of the line in the swamp, with a cut 10 ft. in width, 12 ft. in depth. Horse scrapers were used to remove the first 3 to 4 ft., which had become firm through the drainage work, the remaining material being handled by the clamshell bucket of the derrick, which travelled on a track of 38-ft. gage, carried upon 44-ft. heavy cross ties on one side of this 500-ft. section of the work. The depth of cut increased progressively from 10 ft. to 32 ft. at the south portal. The trench was sheeted by hand, to withhold the quicksand and water which had to be handled. Three sets of sheeting were used, the lowest 16 ft. in depth, followed by 12-ft. and 10-ft. lengths. Where 3 sets were used, the lowest set was 3 in.; elsewhere 2 in. was used.

Four hundred and twenty feet of 54-in. reinforced concrete pipe, made by the Lock Joint Pipe Company at its New Jersey yards and shipped on flat cars to the work, were laid upon a 6-in. concrete base (mixed 1:3:6) extending up to the springing line. All sheeting was withdrawn later, except the bottom course near the south portal. No settlement was observed, and a beautiful pipe line resulted. Three hundred ft. of this line, tested under an internal pressure of 25 lbs. per sq. in., developed very small leakage, well within contract requirements. No leakage was observed at the joints, but there was slight leakage at the bulkhead and from a few pinholes, which closed within a period of 24 hrs. and were later protected by painting the inside of the pipe with cement mortar.

Work upon this section was stopped by cold weather on January 19, 1924.

The cost of the work done by the District is indicated by the following figures:

COST DATA OF WORK UPON THE SEBAGO CONDUIT, DONE BY THE DISTRICT.

Item.	Cost.	Quantity.	Unit Cost.	Estimated Cost.	Low Bid.	High Bid.
Earth excavation	$15 500.00	3 400 c.y.	$4.55	$5.00	$3.25	$9.00
Hauling and laying pipe, exclusive of earthwork	4 439.05	450 ft.	9.85	5.17	1.70	8.50
Concrete foundation and backfill	5 542.83	247 c.y.	22.40	11.50	12.00	30.00
Drain and blow-off	3 587.78	580 ft.	6.70	5.75	...	...
Cost of pipe	7 493.64	...	...	9 600.00	...	...
New road	4 071.20	...	...	2 000.00	...	...

SECTION II: TUNNEL.

After carefully canvassing the general situation, contract was entered into with The Foundation Company of New York, upon March 20, 1924, for the construction of the tunnel section.

Terms of Contract with The Foundation Company. Under the terms of this contract the contractor agreed:

To act "as agent for the District in the execution of the work outlined in said plans and specifications, in a prompt, efficient and workmanlike manner; to accept as compensation for said services" a fee of $15 000 plus plant rental of $4 650.

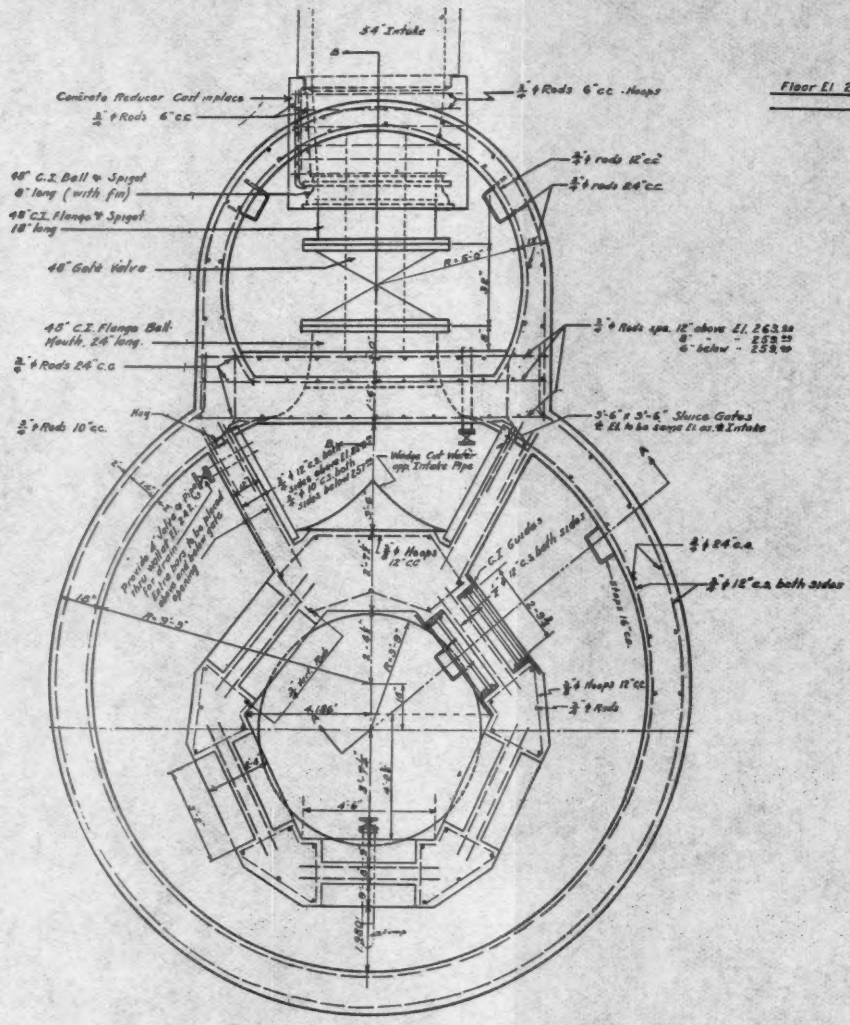
It was "understood that the cost of the work, exclusive of the fee but including plant rental, is estimated at $146 000," and provided that should the cost at completion be less than said sum "one-half the difference shall be added to said fee; on the other hand, should the costs . . . be greater . . . one-half of the difference shall be deducted from said fee. It is further understood that additions to or deductions from the said fee shall not exceed the sum of $7 500."

The term "cost of the work" was defined, and the method of its conduct. A clause was included providing for arbitration in case of dispute as to the proper interpretation of the terms of the contract. A list of plant to be used for the tunnel was appended.

It was estimated that a period of 7 to 9 months would be required for the building of the tunnel, although in fact upwards of 18 months were required.

The contractor began work on March 18, 1924, by transferring an old moving-picture theatre at Smith's Mills Village, across the lake on the ice for his construction camp, which at a later date housed about 80 men.

Shaft. A steel cofferdam, eight-sided, with overall length 32 ft. and width 24 ft., was built with second-hand Lackawanna sheet steel piling 14 in. wide by 30 ft. long. Ninety-two pieces 25 ft. long, and 100 pieces 30 ft. long, weighing 40.8 lbs. per linear ft. (total 108.12 tons) were bought at $47.50 per 2 000 lbs., aggregating a cost of $5 135.70. To date, 131


54" Intake
Concrete Reducer Cast in place
Floor El. 274.00
48" C.I. Ball & Spigot 8" long (with fin)
48" C.I. Flange & Spigot 18" long
48" Gate Valve
48" C.I. Flange Ball Mouth, 24" long.
Key
Weldon Cut Valve opp. Intake Pipe
C.I. Guides
6" Sill
Floor El. 242.92
4" C.I.P. Drain & Valve
El. 238.9

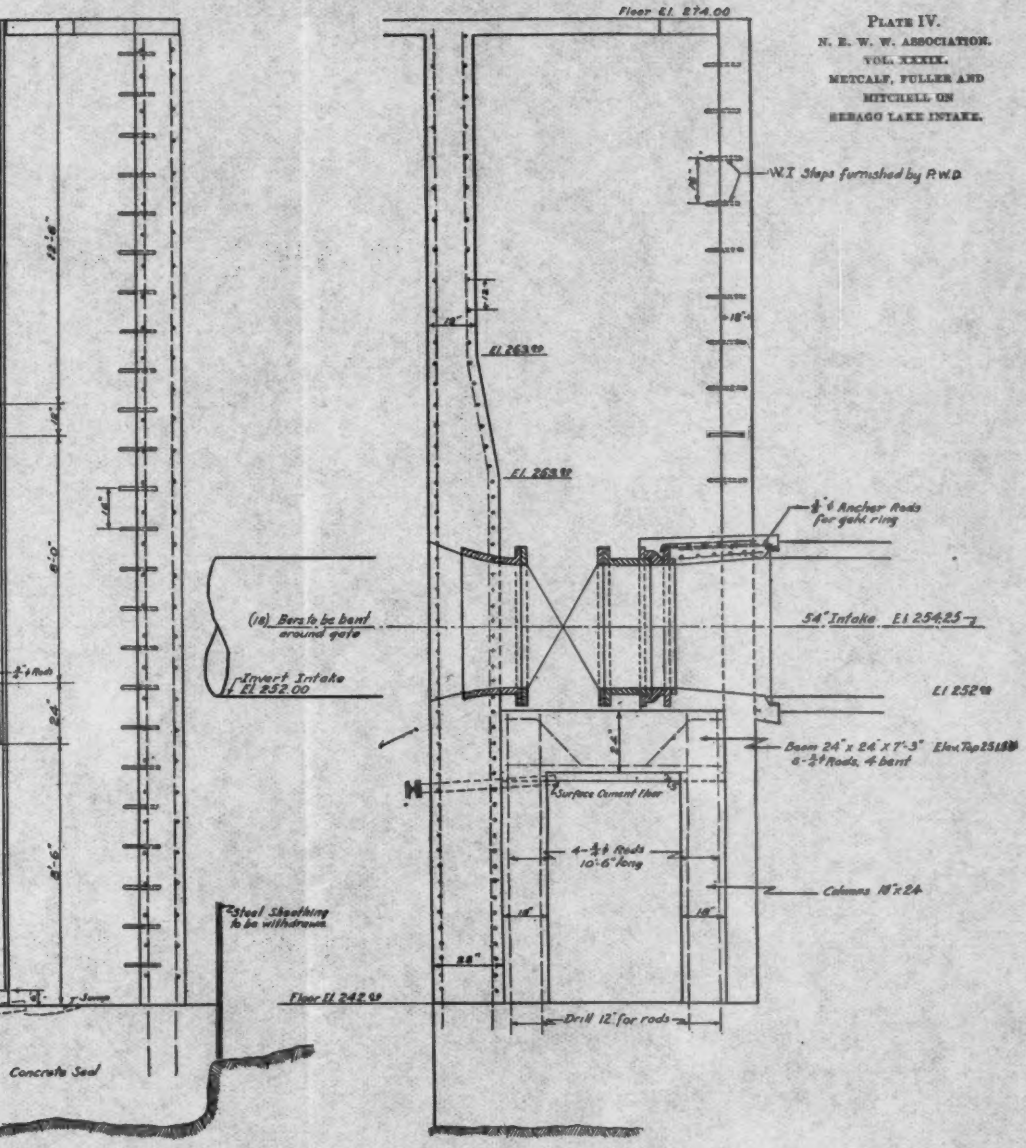
SECTIONAL PLAN

Scale in Feet

0 1 2 3 4 5 6 7 8 9 10

SECTI

SEBAGO LAKE CONDUIT — INTAKE SE



SECTION B-B

ECTION A-A

KE SHAFT AND SCREEN HOUSE.

pieces, weighing 77.15 tons, have been sold at a net price, after deducting freight and cartage, of $36.50 a ton, aggregating the sum of $2 828.75, making the net cost to date $2 306.95. Inasmuch as some of this steel sheeting was used six or seven times during the progress of the work, which covered a total area of 17 182 sq. ft., the resulting cost for the sheeting to date has been approximately 13 cents per sq. ft. of area covered; and its cost in place, including the material, its handling, driving, and pulling, $1.05 per sq. ft.

Material Encountered in Sinking Intake Shaft. In April, 1924, the sinking of the intake shaft at the shore of the lake was begun. For details of the intake shaft and screen house, see Plate IV. The steel piling, referred to above, was driven to ledge at a depth of 30 ft., the earth excavated,

FIG. 1. — INTAKE SHAFT.

and an interior shaft 7 ft. in diameter, 14 ft. deep, was sunk in the ledge to the tunnel heading.

Soil, sand, and gravel were encountered to a depth of 10 ft. from the surface, then a blue clay, with a hard stratum of yellow clay 4 ft. in thickness at a depth of 15 to 19 ft. below the surface.

The cofferdam proved reasonably tight and maintained its shape effectively. In spite of the boulders which were encountered, the piling was driven by steam pile-driver operated by compressed air. The water was handled chiefly by a centrifugal pump.

Within the cofferdam a circular concrete cylinder, 18 ft. 6 in. in diameter, was built upon the ledge, as foundation for the gate house, and inside it a smaller cylinder, 7 ft. in diameter, 44 ft. deep, in which are to be located the 5 double sets of screens through which the water will pass from the intake before entering the tunnel. (See Fig. 1.) The smaller interior cylinder

is located eccentrically with respect to the outer cylinder, thus decreasing the width and the area of the channel of approach to the screens as the water passes from the intake to the screens and through them into the tunnel below.

While the wash-drill borings had indicated that a depth of 45 ft. below the surface the tunnel would have adequate roof cover and that the depth of this cover would increase progressively, when the foundation excavation in the cofferdam had been completed, it was found that the ledge cover was inadequate and so disintegrated as to make it unwise to attempt to start the tunnel heading at this point and run the risk of heavy leakage in this short section of tunnel between the lake and the point at which the depth of cover might be found to be adequate.

The core-drill borings, heretofore referred to, were therefore made under "rush" contract with the B. F. Smith Company, to determine the level of sound ledge, in advance of the work. These borings indicated that by slightly modifying the original line, adequate cover could be obtained at a distance of about 70 ft. from the shaft, and a new shaft was therefore built at this point, the intervening section of conduit being built in open cut 45 ft. in depth, in a trench sheeted with the steel piling.

The new construction shaft was begun on September 19, 1924. Despite the indications of the additional core-drill borings, which had been made on July 19, after a distance of 70 ft. from the shaft had been traversed by the tunnel, with its excavation 7 ft. in diameter, a large cavern was encountered in the heading, about 9 ft. in diameter and 7 ft. high, directly overhead. During the first two days after reaching this, the cavern was practically dry, but on the third day, as the roof of the tunnel was being timbered, a stream of water began to trickle through, followed shortly by a rush of sand and water which filled a 60-ft. section of the tunnel and opened a hold from its roof to the surface of the ground 50 ft. above. A timber-lined shaft 12 ft. by 12 ft. was then sunk at this cave-in and a concrete seal made over the roof of the tunnel. The sand and gravel which had run into the tunnel was excavated and the heading again started.

After going about 9 ft. more, soft rock was encountered again. The heading being made safe, explorations were made along the line of the tunnel, with a core drill, and from one head with diamond drill. While these borings were rather unsatisfactory because it was found impossible to hold the drills on a straight line, they disclosed bad ground for a considerable distance ahead.

This adverse condition, coupled with the difficulties already encountered with the fine quicksand at the southerly portal of the tunnel, and the possibility of encountering further soft ground ahead, in spite of the indications of the earlier borings, led to the decision to put compressed air on the tunnel work.

Compressed-Air Equipment Installed. Accordingly, compressors, pipe lines, and air locks were installed, and on December 7, 1924, the head-

ing was opened and drilling begun with 11 lbs. per sq. in. of air pressure in the headings. At the same time the period of labor was changed from two 10-hour shifts to three shifts of 8 hours each. Trouble was anticipated with the labor, due to the installation of compressed air, but failed to develop. It is interesting to note that the only trouble encountered with labor came when the air was removed, the men objecting to working in a wet heading after working in the dry heading with the air on.

Pressures slightly above 15 lbs. per sq. in. were found necessary at different points in the work.

Since the introduction of compressed-air methods on December 7 the heading at the lake made steady progress until May 21, 1925, when it met the heading from the south portal. In this period of 164 days, 16 days were spent concreting when no progress was made in heading. This leaves 148 days driving the tunnel from Sta. 2+15 to 14+55 or 1 240 ft., or an average of 8.38 ft. per day. During this period, 16 days were spent in lining 162 ft. of the tunnel with concrete, to prevent air leakage and danger from bad ground.

The average drilling for the heading consisted of 17 holes 6 ft. deep. Eight sticks of 60 per cent. gelatine powder was the usual charge per hole, the holes being fired in three rounds using instantaneous, first-delay and second-delay exploders, the time required for the three rounds being about 15 seconds. The average shot pulled about 5 ft. of heading. As soon as the tunnel cleared of smoke, drilling and mucking was begun, the muck pile serving as a bench on which to stand while drilling the top holes. Air-driven jack hammers were used, and small muck cars pushed by hand over an industrial railway track laid in the tunnel.

The rock varied from soft mica schist to hard quartzite, with occasional thin and very hard layers without cleavage, resembling trap rock. The overburden varied from fine quicksand to coarse gravel and free sand. Mechanical analysis of the material which entered the tunnel in one of the runs at Sta. 20, indicated an effective size of 0.072 mm., 60 per cent. finer than 0.13 mm., a uniformity coefficient of 1.81, and a fineness modulus of 0.321. The material at the easterly end of the tunnel was somewhat finer than this.

South Portal and Land End of Tunnel. The south portal of the tunnel was located at the foot of a steep bank or terrace of sand, the shaft dropping 35 ft. below the surface of the ground, as previously stated. From this shaft the tunnel extended a distance of 160 ft. before rock was encountered in the bottom, and 245 ft. further before rock was of a sufficient height for a full rock heading. The first 201 ft. of this tunnel were excavated without the use of compressed air, at an average daily progress of but 10 in. — a heart-breaking process — not to mention the heavy cost involved. The remaining 204 ft. were excavated under air pressure ranging from 5 to 10 lbs., at an average daily progress of 3 ft. It was found that higher pressure could not be maintained, due to the character of the material and the

leakage of air into the ground along the tunnel; and no clay was found suitable for plastering the face of the heading.

This entire section of the tunnel was driven by means of poling boards of 2-in. tongued and grooved Georgia yellow pine 6 in. wide. Seven-foot poles were driven at an upward angle of about 20° over a 10-in. x 10-in. oak cap having a wedge-shaped plate attached to the top of it. Next the poles were driven down the sides with an outward flare of 20°. Then the face was broken through at the top, and the muck either flowed or was pulled by hand into the tunnel and carried back in cars to the shaft through which it was raised to the ground by elevator. As soon as sufficient muck was excavated, a temporary 10-in. x 10-in. cap was placed at a distance of about $2\frac{1}{2}$ ft. from the permanent cap, as were foot blocks, wedged into the bottom, and short temporary posts. Another 3-ft. section was excavated and a permanent 10 in. x 10 in. cap was placed in like manner, but having a bevelled plate on top of it for driving the next set of poling boards. This top bench was then excavated to a depth of 3 ft.

Before excavating the bottom bench it was necessary to drive small cofferdams of 1-in. tongued and grooved boards, with the aid of bags of concrete to hold back the material until a solid foundation could be secured for 2-in. x 16-in. x 24-in. foot blocks wedged down from the roof, upon which permanent posts of 10-in. round timber were then placed. This involved slow and anxious work and seriously retarded progress.

As soon as a 6-ft. section was bottomed out, a 6-in. concrete base of 1:3:6 mixture was placed. Where ledge was encountered within 18 in. of the floor of the tunnel, the concrete was carried to the ledge. Side walls, 3 ft. high, were poured with this base, thus strengthening the permanent posts. As the tunnel progressed, the intermediate caps were replaced by 6-in. H-beams 7 ft. long, carried on wooden posts.

When tunnelling had progressed about 100 ft. from the south portal, three successive bad runs occurred in the heading, which was nearly lost. This was the darkest moment of a terribly anxious experience. Collapse was averted only by the experience and vigilance of the foreman, Donald Knight, and the confidence of his crew in him. Fighting inch by inch to hold the material, with progress at a standstill for 12 days, the expedient of grouting this material (fine siliceous sand) was tried. For ten days and nights grout was poured through 2-in. pipes, from the surface of the ground to points immediately ahead and above the bad ground surrounding the line of the proposed tunnel. While this process did not thoroughly compact and harden the ground, it did stiffen and dry up the quicksand sufficiently so that tunnelling progressed for a distance of 20 ft. From this point until the air was put on, it was necessary to grout ahead of the working face before breaking through. This was done through horizontal pipes. The total amount of cement used in these grouting operations was 418 barrels, of which 125 barrels were placed from the surface.

As the ledge rose toward the arch of the tunnel many large boulders

were encountered, which greatly increased the area of the masonry section in tunnel in these places. It has been suggested by geologists that the outlet of Sebago Lake may in prehistoric times have been at this point, rather than at its present location. At all events it is clear that the glacial ice sheet in moving past this section scored deeply the underlying micaceous rock and deposited strings of large boulders, both of which served to materially increase the cost of this work.

When compressed air was introduced the lock was installed in the southerly portal at a point about 200 ft. from the shaft, and a section of the tunnel extending 60 ft. outside of the lock was concreted and grouted. Even this failed to hold the air and in many places as far back as the shaft, 200 ft. distant, the air was observed coming in from both sides and from the bottom at certain times, bringing in considerable amounts of material. For example, at one of these periods 3 cu. yd. of extremely fine material, probably less than 0.05 mm. effective size, were handled before the leak could be stopped.

Several fractures showed on the surface of the ground 70 ft. above the tunnel.

As soon as the tunnel was holed through, the concrete lining was begun in soft ground, under normal air pressure. This concrete was placed by hand, the concrete being reinforced by a double row of hoop steel of $\frac{1}{2}$-in. round bars spaced 5 in. on centers. Five-foot sections were poured at a time. At certain points it was necessary to cut into the wooden caps of the arch, to allow for reinforcement and to facilitate the placing of the concrete — difficult and dangerous work because of the squeeze of the material, which actually resulted in the snapping of some of these beams. In these top spandrels the concrete was placed fairly dry and carefully rammed between the caps.

The compressed-air service was interrupted but three times during the progress of the work, — once by a very heavy storm when the pressure was off for $1\frac{3}{4}$ hours; the second time while making repairs for a period of 50 minutes the air pressure fell from 15 lbs. to 9 lbs.; the third time, also while repairs were being made, for a period of $1\frac{1}{4}$ hours the pressure was reduced from 16 lbs. to 11 lbs. No damage resulted from any of these interruptions to full air service.

Labor Cost. Unskilled labor was paid 40 cents per hour on top and 50 cents per hour in tunnel. This was increased to $62\frac{1}{2}$ cents per hour when air was installed. Skilled labor commanded rates of from 70 cents to $1 per hour. Labor worked 10 hours on the surface, and in the tunnel on three shifts of 8 hours each.

Contractor's Plant. The contractor's plant, used in the sinking of the caisson and the driving of the tunnel, consisted of the following machinery:

One No. 7 Union Iron Works steam pile-driver operated by compressed air;

Two stiff-legged derricks with 60-ft. boom, of 12 x 12 yellow pine, with

hoisting-engine of the American Derrick and Hoist Company, electrically driven by 35 h.p. motors;

One Chicago pneumatic air compressor electrically driven by 37 h.p. motor; run all the time, capacity 350 cu. ft. per min. at 100-lb. per sq. in. air pressure;

One Ingersoll-Rand compressor electrically driven by 60 h.p. motor; capacity 360 cu. ft. per min. at 100-lb. per sq. in. air pressure, spare machine;

Two Worthington air compressors, electrically driven by 100 h.p. motors; capacity 600 cu. ft. per minute each, — one at 100 lbs., the other at 30 lbs. per sq. in. air pressure, — run constantly;

Pressure air receivers:

One $5\frac{1}{2}$ ft. diam., 19 ft. long, 450 cu. ft. capacity, 30-lb. pressure;
One $3\frac{1}{2}$ ft. diam., 16 ft. long, 150 cu. ft. capacity, 100-lb. pressure;
One $2\frac{1}{2}$ ft. diam., 6 ft. long, 30 cu. ft. capacity, 100-lb. pressure;
One 3 ft. diam., 6 ft. long, 40 cu. ft. capacity, 100-lb. pressure;
One 4 ft. diam., 6 ft. long, 75 cu. ft. capacity, 100-lb. pressure;

One Lambert electric hoist, driven by 37 h.p. motor;

One Lambert hoist driven by 4 cylinder Automatic Machine Co. (Bridgeport) gasoline engine;

One Ingersoll-Rand No. 50 Leyner drill sharpener;

Twelve Ingersoll-Rand B.C.R. No. 430 jack hammers;

Two Ingersoll-Rand No. 56 clay spaders;

Six Koppel cars — 1 cu. yd. capacity with 2 500 ft. of 2-ft. gage industrial track;

One Lawrence 4-in. centrifugal pump and one 6-in.;

Two Cameron No. 5 pumps;

One $\frac{3}{4}$-yd. Ransome concrete mixer;

One Ransome grout gun, capacity 1 bag, 1:1 cement and soft sand;

One Ransome pneumatic concrete placer, capacity 8 ft. per charge, three charges to the batch, about 10 minutes to the batch, 40 cents per cubic yard royalty;

One 1-bag Boss concrete mixer, used also in Section III;

One circular saw table, driven by 2 h.p. motor;

One pump for water supply — Rumsey — 10-in. stroke, 6-in. suction, 5-in. discharge, reduced to 2 in., driven by 5 h.p. motor;

Two air locks, 5 ft. x 5 ft. x 13 ft. long, with doors 4 ft. x 4 ft.;

Blaw-Knox circular steel forms for 60-in. lining; 5-ft. sections; 25 ft. section pouring; 90 ft. of forms used.

Transportation Machines :

One 1-ton Ford truck;
One 1-ton Ford dump truck at gravel pit;
Two Ford light trucks for engineers and superintendent;
One Dodge touring car for administration.

Power Equipment. Electric power lines were extended to the site of the work from the transmission lines of the Cumberland Power & Light Company, carrying electric current at 11 000 volts, at the cost of the Portland Water District, one line running through the woods and swamp along the line of Section III, carrying a tension of 2 300 volts stepped down to 440, and another line along the main road to Sebago Lake, serving the shafts and surface plants with current stepped down from 2 300 to 440 volts.

All electric transmission on the work at 440 volts and under was done by the contractor. Twenty-three hundred volt lines were maintained by the Cumberland Power & Light Company at the cost of the District. All transformers were bought at the cost of the District, but are to be resold by the Power Company at the end of the job, on account of the District.

Twenty-six transformers were used:

Three 60 k.v.a. 11 000 to 2 300 volts;
Six 40 k.v.a. 2 300 to 440 volts;
Six 37½ k.v.a. 2 300 to 440 volts;
Four 25 k.v.a. 2 300 to 440 volts;
Seven small lighting transformers 440 to 110 volts;
Connected motors aggregating 640 h.p.;
300 light outlets;
Cost of electrical installation, transformers and power lines $6 000;
Rate for electric current $1 per h.p. of actual demand per month (about one-half of 640 h.p. of connected motors) plus 1.2 cents per kw. hr.

The monthly bill for electric power during the active season was about $1 600.

Concrete Aggregate — Gravel and Sand. A good deposit of sand and gravel was found about 800 ft. from the gate house at the lake front. The pit opened in it furnished a good, hard resistant clean gravel and sand, which proved better under test than other local sands, but an overburden of 18 in. of loamy sand and 30 in. of sand the greater portion of which was wasted had first to be stripped from the site. Thereafter a 12-ft. to 16-ft. working face was obtained.

In the first year of construction the material was obtained and hauled by horse scrapers from the bank to a platform and chute from which the material was carried by bucket belt to and separated by an elevated rotary screen of ¼-in. to 2½-in. mesh, 12 ft. long, the materials being deposited in three bins containing sand, stone, and tailings. The tailings were carted from the bin to the No. 2½ Climax crusher, from which after crushing the material was reconveyed to the rotary screen. Two 20 h.p. motors furnished the power, one running the crusher, the other the screen and elevator. Delivery was made by a Ford 1-ton dump truck or tractor with dump trailer, or by teams. The 1-ton Ford truck proved the quickest and cheapest method of handling the material.

In the second year the sand and gravel were taken from the pit by a small Hoar tunnel mucking shovel, operated by air, loading into Koppel cars hauled to the crusher by gasoline donkey engine, — necessary because of increasing length of haul from the pit.

Character of Material and Cost. The run of the pit averaged 25 per cent. of stone, the maximum being 40 per cent. The average run per day was about 35 cu. yd. of stone, the unused sand being wasted.

The relative quantities of gravel, sand, and waste are indicated by the following observations:

Gravel	2 570 cu. yd.	36.4%
Sand	1 914 cu. yd.	27.1%
Waste	2 568 cu. yd.	36.5%
Total	7 052 cu. yd.	100%

The cost of the gravel and of the sand used was $2.57 per cu. yd., including overhead but excluding engineering costs. Had there been demand for the excess of sand, the average cost of the material would have been but $1.63 per cu. yd.

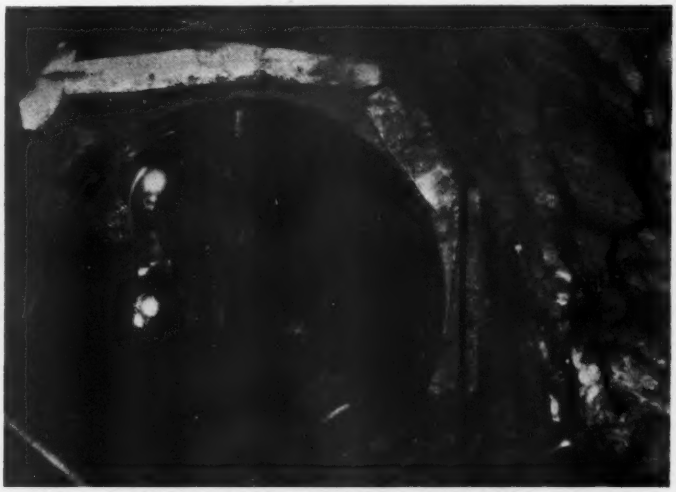


FIG. 2. — METHOD OF CONSTRUCTING TUNNEL.

Placing Concrete Lining. The concrete was mixed on the surface at the shafts, dumped into chutes down the shaft discharging into Koppel cars upon the industrial railway track in the tunnel, the car being pushed forward by hand to the point of lining. The concrete was discharged by gate in the end of the car, upon a steel platform on the floor of the tunnel. From this it was shovelled into a helical conveyor discharging into the hopper of a Ransome concrete gun, the concrete being discharged from the latter into the forms, through a 6-in. rubber hose. Much spading was found to be necessary, to place the concrete well. Five per cent. of hydrated lime was found advantageous, to make the concrete work better behind the forms. The placing of this concrete was tried first without the use of the hydrated lime, but it was found very difficult to make the men work it sufficiently to get a dense, compact mass. The tunnel during construction is shown in Fig. 2.

Water Encountered. It was found impossible to get accurate measurements of the flow of water in the tunnel, because of the intermittent method of its expulsion. The approximate gagings indicated on

February 24, 1925, with normal air and heading at Sta. 7+51, ground water leakage estimated at..... 40 000 gal. per day.
March 26, with normal air and heading at Sta. 10+08 leakage..... 150 000 gal. per day.
July 27, with normal air and heading at Sta. 11+14, when concreting, leakage..... 90 000 gal. per day.
The last observation indicated,
With air off, about..... 850 000 gal. per day.
With 10-lb. air pressure..... 100 000 gal. per day.
With 13-lb. air pressure..... 50 000 gal. per day.
With 15-lb. air pressure substantially no leakage.
The latter observations were, however, crude.

Overbreakage. The record of overbreakage in rock is interesting. It reflects first the disadvantageous character of the rock, and second the fact

Station.	Distance in feet.	Average area removed.		Per cent. overbreakage in excess of	
		Sq. ft.	Diam. of equiv. arch.	Pay Section (38.48 sq. ft.)	Masonry Section (18.84 sq. ft.)
1 + 32 to 2	68	52.57	8 ft. 2 in.	37	75
2 to 3	100	59.73	8 ft. 9 in.	55	113
3 to 4	100	48.56	7 ft. 10 in.	26	53
4 to 5	100	55.55	8 ft. 5 in.	44	91
5 to 6	100	53.50	8 ft. 3 in.	39	80
6 to 7	100	51.70	8 ft. 1 in.	34	70
7 to 8	100	47.33	7 ft. 9 in.	23	47
8 to 9	100	47.03	7 ft. 9 in.	22	45
9 to 10	100	45.31	7 ft. 7 in.	18	36
10 to 11	100	41.12	7 ft. 3 in.	7	14
11 to 12	100	58.26	8 ft. 7 in.	51	105
12 to 13	100	45.48	7 ft. 7 in.	18	37
	1 168	50.5*		31	64

* Weighted average.

that the change in method of driving from open air to compressed air somewhat increased the section of material which had to be taken out, to give room for air pipes. The breaks in the roof cover also resulted in materially increasing the overbreakage.

In discussing the overbreakage it is to be remembered first that the pay section was fixed at 12 in. in thickness (outside of the 60-in. internal diameter of lined tunnel); second, that an average thickness of but 9 in. of masonry was permitted; and third, that the minimum thickness for limited areas was fixed at 6 in. This means that the excavation to be paid for corresponded to a circle 7 ft. in diameter, or 38.48 sq. ft.; the permissible average section, to 6 ft. 6 in. in diameter, or 33.18 sq. ft.; the clear waterway

to 5 ft. diameter, or 19.64 sq. ft. The actual average section removed in a distance of 1 168 ft. was 50.5 sq. ft., equivalent to a circle about 8 ft. 0 in. in diameter. In other words, the overbreakage averaged 6 in. in diameter greater than the pay section, giving 31 per cent. greater cross-section of excavation and 64 per cent. greater masonry section than the pay limit.

Cost per Linear Foot of Lined Tunnel. The total cost, including overhead and engineering, was about $172 per linear foot of tunnel.

Section I: Lake Intake.

After carefully canvassing the general situation the Portland Water District entered into contract, under date July 8, 1924, with The Founda-

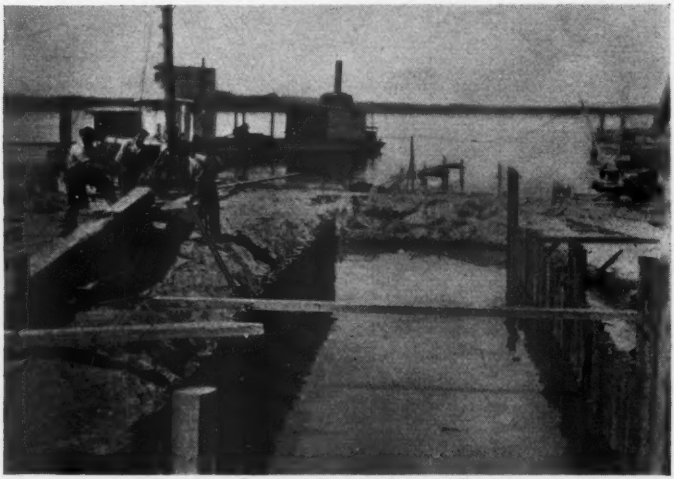


Fig. 3. — Section I, from Intake Shaft.

tion Company, for the construction of Section I, Intake, and Section III, South Section, of the new conduit.

The general terms of the contract were similar to those for Section II. The agreed rental for plant for the construction of these sections was $1 675, exclusive of two scows, for the purchase of which the District was to make its own arrangements. For its service The Foundation Company was to receive 10 per cent. of the cost of the work, with an upset limit of $9 000.

It was agreed further that the cost of the work should "include a proportional charge for the use of the camp, temporary buildings, water supply, fuel and current charges, and general job expense, which charge shall be credited to the existing contract for Section II . . . which was to be estimated at 25 per cent. of the other items of cost in making up this contract, excluding the fee, but including plant rental."

The lake section comprised the laying of 1 580 ft. of 54-in. reinforced

concrete pipe from the gate and screen house at the shore to an elliptical bellmouth at the lake end.

The first 200 ft. were laid in open cut, by the use of Lackawanna steel piling, 25 ft. in length (see Fig. 3), driven by the steam hammer in the same manner as in building the gate-house cofferdam. No particular difficulty was encountered in keeping this trench pumped out and laying the pipe in the dry.

The transition from the rigid support for the pipe in the gate house to the support of the bottom of the trench was made by means of a reinforced concrete slab laid under the pipe, supported rigidly on the gate-house foundation, resting at its outer end on the bottom of the trench.

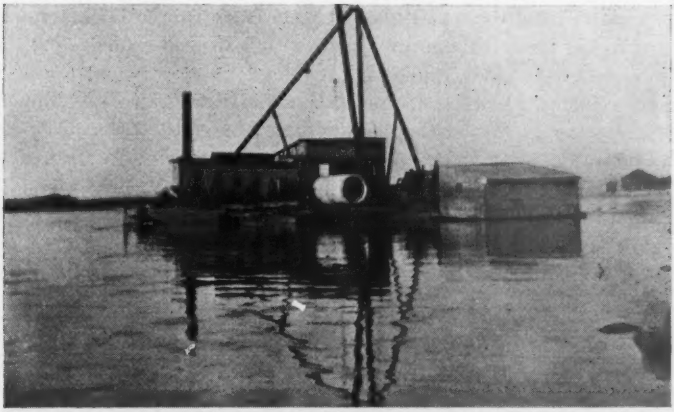


FIG. 4. — LAKE INTAKE. 54-INCH CONCRETE PIPE READY TO LAY.

The depth of excavation decreased from 18 ft. at the shore end to nothing at the outer end. The trench in the lake section varied from 8 ft. to 0 ft. over a distance of about 1 200 ft. It was 8 ft. in width, the banks under water standing nearly vertical. After laying the pipe the trench was backfilled to the top of the pipe.

Work on this section was shut down on December 22 when the lake froze over, and was resumed on April 20, 1925.

The excavation in the lake was made by a $\frac{3}{4}$-yd. clamshell bucket operated by a stiff-legged derrick with 60-ft. boom of 12-in. x 12-in. yellow pine timber with steam hoist, all mounted on a derrick boat (Fig. 4).

This derrick boat consisted of two scows 60 ft. long and 20 ft. wide, lashed together by six 12-in. x 12-in. yellow pine timbers subsequently stiffened by the addition of six 10-in. I beams 44 ft. long.

The scows were held in place without difficulty by four anchors with $1\frac{1}{4}$-in. diameter Manila rope. Four sets of dolphins, consisting of 3 oak piles each, were also driven at intervals of 500 ft. along the lake intake, with two located at its outer end.

After dredging the trench under water, the pipe was laid by two divers in the following manner: first, a set of concrete ties 6 in. x 6 in. x 6 ft., with $\frac{3}{8}$-in. steel reinforcing bars in the corners, was laid across the trench to grade, 1 ft. back from each end of the pipe. Upon these ties the pipe was then lowered and placed by the divers. One and one-eighth in. eye bolts having been secured previously in the 4-in. inserts cast into these pipes 12 in. from their ends, 26-in. by 1-in. steel bolts were inserted into the eye bolts and the lengths of pipe drawn together by the divers. These bolts, being placed on the horizontal diameter, give free opportunity for vertical motion and worked very satisfactorily. When two pipes had been laid, concrete in cement bags was placed under the haunches over the slabs, to hold the pipe securely in place and distribute the pressure. The divers then entered the pipe and calked the lead ribbon gaskets made by the Lock Joint Pipe Company, and filled the jointing space with a bagged cement "sausage" held in place by the reinforcement left for this purpose. No work was done upon the cementing of the joint on the outside of the pipe. No difficulty was experienced in this method of jointing. Later the trench was backfilled to the top of the pipe by the clamshell dredge, with the material previously excavated.

While the pipe was being calked by the divers, the trench excavation continued ahead. Until the trench reached a depth of 3 ft. a night crew of three men was necessary on the excavation, to keep ahead of the 10-hr. day crew.

The bellmouth at the end of the pipe was 7 ft. long, with a spigot piece cast into the inner end. The outer end was elliptical in form with 6-ft. 9-in. major axis and 5-ft. minor axis, making the velocity at entry two-thirds of the velocity in the 54-in. pipe. The bellmouth was set at a depth of 26 ft. below mean lake level with its lower lip 2 ft. above the bottom of the lake. Copper rods are placed across the opening, to prevent the entry of large bodies into it. The top of the bellmouth will have about 18 ft. of water over it at mean lake level, 15 ft. at legal low water mark, and nearly 23 ft. at high lake level. The shallowness of cover over the pipe in the lake was justified by the experience with the old 48-in. cast-iron intake, which though laid but $3\frac{1}{2}$ ft. below low water and 7 ft. below mean lake level at the point where it emerges from the bed of the lake, and $10\frac{1}{2}$ ft. at the intake end, has given no trouble in the past, either from ice or other disturbing causes.

Fifty-four Inch Reinforced Pipe Contract with Lock Joint Pipe Company. On the work of pipe-laying done by the District in Section III in the swamp, in the fall of 1923, the forty lengths of 52-in. reinforced concrete pipe were bought from the Lock Joint Pipe Company. They were made at its Ampere, N.J., works and shipped to the work, three pieces of pipe on a flat car constituting a load. The pipe cost $15 per ft., f.o.b., Sebago Lake.

For the main work in the following year the District entered into contract with the Lock Joint Pipe Company under date August 20, 1924.

The contract contemplated the making of 239 pieces of 54-in. reinforced concrete pipe in 12-ft. lengths, with walls $5\frac{1}{2}$ in. in thickness; 250 pipes were finally made. These pipes were to be furnished in accordance with the original plans and specifications of April 18, 1923, and the detailed specifications submitted by the Lock Joint Pipe Company.

The contract provided, amongst other things, that all plant equipment, materials, and labor entering into the manufacture of the pipe, except sand and crushed rock, should be provided by the contractor; that 129 pieces of pipe, more or less, to be used in the intake, should be provided with nipples in the wall of the pipe, to take the eye bolts used for drawing the joint up under water; and the contractor should furnish the necessary number of sets of four eye bolts and two bolts with nuts; furnish the necessary

FIG. 5. — CONCRETE PIPE PLANT.

gaskets; provide a competent man to supervise and assist in the making of joints; that the pipe should be tested at hydrostatic pressure at least 50 per cent. in excess of the static head from high water in Sebago Lake, maintained for at least 30 minutes; and that the entire leakage under such pressure should not exceed a rate of 2 400 gal. per 24 hours per 1 000-ft. section of pipe (this requirement was substantially bettered); that the contractor begin delivery August 21 and complete the same October 3, 1924; that the District should furnish site for the contractor's plant and the necessary crushed rock or gravel and sand of suitable size and quality, without cost to the contractor; pay the regular wages of the men employed in making joints; and pay for the pipe the sum of $15 per ft. and, in addition thereto, $4.50 for each set of eye bolts and bolts with nuts.

It was agreed, further, that the contractor might board his crew at

the boarding-house maintained by the District, but should provide sleeping quarters for them at his own expense.

On July 25, 1924, the contractor began work upon his plant for making reinforced concrete pipe. On August 19 the first pipe was poured and thereafter eight pipes per day were made. Each pipe was cured by steam under canvas, for four days. The last of the 250 lengths of this pipe, made for the District in 1924, was poured on October 10. The crew involved in the making consisted of 12 to 15 men; the plant, of one stiff-legged derrick with 50-ft. boom and steam hoist, two 1-bag concrete mixers of the conical end dump type, and 8 steel molds for the pipe (Figs. 5 and 6).

The pipe was generally poured after the noon hour, and stripped early on the following morning, and thereafter covered with canvas and cured

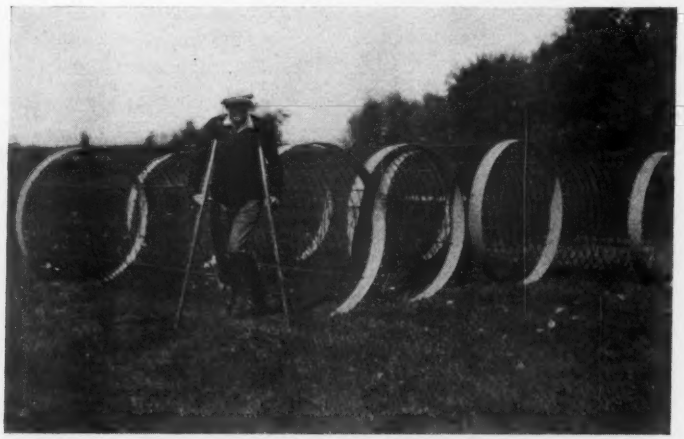


FIG. 6. — REINFORCING CAGES FOR 54-INCH CONCRETE PIPE.

by steam. On the fourth night after pouring, the pipe was turned and rolled onto the skids in the storage yard, remaining there 14 days or more before use.

The pipe used on the lake intake was rolled from the skids onto a float supported by 55 empty oil barrels, and towed by motor boat about 1 000 ft. to the derrick boat, by which it was unloaded and immediately placed in the line under water.

The pipe used in Section III was hauled one-half mile on a heavy jigger holding one pipe by a Fordson tractor and six horses. Each pipe weighed about 6½ tons. Four pipes were hauled per day. This hauling was done under contract at a price of $2 per foot for loading, hauling, and delivering beside the trench.

As previously stated, the sand and gravel were furnished to the contractor by the District, free of cost, the cost to the District being about $2.57 cu. yd., including overhead but excluding engineering costs.

The concrete for the pipe was mixed in the proportion of 1 part cement, $1\frac{3}{4}$ parts sand, and $2\frac{1}{4}$ parts gravel, — experiments being conducted to determine the most advantageous size of the gravel.

Cost of Intake Section. The total cost of the intake section was approximately $54 per linear foot of pipe line, furnished and laid complete, the cost of the pipe itself amounting to slightly under $18.

Section III: Swamp and Land Section.

This section of the conduit consists of 1 900 ft. of 54-in. concrete pipe laid partly through swamp, partly through firm ground, connecting the south portal of the tunnel with the old 42-in. and 30-in. cast-iron mains running to the city. The laying of the first 480 ft. of this section by the District in the fall of 1923 has already been described.

On July 15, 1924, The Foundation Company began work upon Section III under its contract, at the blow-off pipe where the District had terminated its work.

The use of the travelling stiff-legged derrick with 50-ft. boom and electric hoist of the American Hoist and Derrick Company, driven by $22\frac{1}{2}$ h.p. motor, was continued. The pipe was laid in a sheeted trench about 8 ft. deep, with a 6-in. concrete base beneath it and extending up to the mid-diameter, through the swamp section, the drainage being taken care of through the blow-off pipe. When solid ground was reached, the pipe was laid without concrete base, but with a little mortar to spread the load and prevent rolling.

Excavation was made by the derrick in the wet work and by slip scrapers when the swampy section had been passed. The deepest cut, about 18 ft., was excavated by means of two-horse drag scrapers after loosening the hard clayey soil with a plow.

The pipe-laying gang consisted of one engineer, three laborers, one calker, and one helper. The method of jointing was that ordinarily used by the Lock Joint Pipe Company, — with lead ribbon gaskets calked from the inside, covered with cement mortar, held in place by reinforcement and with cement mortar on the outside of the joint, held in place with canvas saddle. The pipe was laid on straight line and grade to a summit in deep cut, where the two ends of the pipe were connected by a reinforced concrete collar.

The connection between the concrete and cast-iron pipe was made by a 4-ft. cast-iron spigot cast into the end of the concrete pipe, using angle bars tapped into the cast-iron pipe to secure it in place. At the air summit a 2-in. brass tee was cast into the concrete pipe for attachment of an air valve.

Entry into the pipe line is provided through a standard boiler manhole located near the blow-off connection.

In making the 12-in. blow-off connection, the concrete was cut out of the section and the reinforcing rods were cut and bent outward along the line of the blow-off connection. A concrete block was then cast around

these rods and the 12-in. blow-off branch, on which was placed a 12-in. gate. This in turn discharged into a 20-in. open joint tile drain 800 ft. long, more or less, with free discharge to the brook, a vertical 24-in. tile vent pipe being provided close to the gate, to prevent serious surcharge upon the drain.

The earth cover over the pipe varies, but is about 3 ft. in depth.

Near the terminus the new conduit crosses a small brook. Here a box culvert was built of reinforced concrete 55 ft. long, in line with the stream

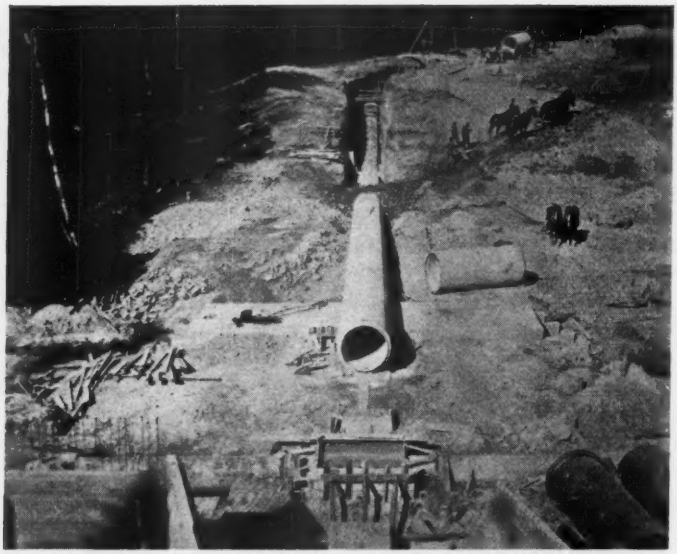


FIG. 7. — CONCRETE PIPE NEAR CONNECTION WITH EXISTING MAINS.

and with waterway $6\frac{1}{2}$ ft. high and 10 ft. wide (Fig. 7). Seven concrete piers were built, with connecting longitudinal beams upon which the pipe was laid in the approaches to the culvert, and thereafter covered with embankment extending 3 ft. above the top of the pipe.

Connection between Conduit and Old Mains. The new 54-in. reinforced concrete pipe was reduced at its end to a 48-in. cast-iron spigot. The crossing and connection with the old 42-in. and 30-in. cast-iron pipes was made with 48-in. cast-iron pipe, terminating in a 42-in. plugged cross providing for connection with a future conduit leading to the city. Between the old 42-in. and 30-in. supply mains on the 48-in. new main is a 48-in. connection, discharging through a 48-in. x 24-in. master Venturi meter, the discharge of which reconnects with these mains and with independent 42-in. and 30-in. Venturi meters on the individual lines.

By these means water may be fed directly to the city in the 42-in. high-service line or back to the Basin, and thence to Ward's Hill through

the three old mains, — 30-in. cast-iron and 26-in. and 20-in. wrought-iron cement-lined pipes.

To house the Venturi meter and facilitate chlorination of the entire supply at one point, a meter and chlorine house was built, one story high with foundation, 30 ft. long and 10 ft. wide, with four compartments for chlorine storage, chlorine apparatus, Venturi registers, and fuel storage respectively. There is no direct connection between the chlorine apparatus or storage chambers and the Venturi meter room and basement. To enter one from the other, one must first pass out of doors. A plate-glass window is provided, however, between the two, by means of which the Venturi meter register may be read while working upon the chlorine apparatus. The Venturi meter and gates are housed by concrete chamber, giving ready access, backfilled with earth, with a 2-ft. depth of cover. About 2 000 cu. yd. of earth had to be moved in excavating and grading around the culvert, and the Venturi meter and chlorine house.

Files Field Cross Connection. At Files Field, about ½ mile nearer the city, a cross-connection between the 42-in. and 30-in. lines had to be made in anticipation of the work of connecting the new conduit with the old. This connection was made under pressure by Smith tapping machine with sleeve and gate, using 20-in. pipe and controlling gates. This permitted either line to be thrown out of commission temporarily, while making connections at the Venturi meter house, between the new 54-in. Sebago Lake conduit and the old lines.

Cost of Section III. The special structures, Venturi meter and chlorinating house manholes and culvert, cost about $26 000, and the total cost of furnishing and laying the 54-in. reinforced pipe in Section III was about $30 per linear foot for the 1 440 ft. of pipe laid by The Foundation Company. Of the latter amount the pipe alone cost about $17 per linear foot.

Progress. Despite the fact that the entire work was carefully and intelligently handled by The Foundation Company, the relatively slow progress and increased cost over the original estimates, both of engineers and contractors, indicates the serious nature of the difficulties encountered in handling the tunnel and its connections, in the quicksand and rock encountered.

Accidents. In passing, it may be noted that but one serious accident occurred throughout the period of construction. In February, 1925, when at about mid-tunnel, after a blast at the heading, it was noticed that one or more holes had not blown out to full depth, 2 ft. of the drift apparently remaining unshattered. After measurement the foreman concluded that the charge had blown and, instead of reloading the hole and blowing again, attempted to deepen the hole with jack hammer drills. There was an instant explosion which seriously injured two drillers and their two helpers, their flesh being badly lacerated by small stones; wrists and ankles fractured, and ear drums broken. One man had concussion of the brain and another a broken pelvis. Hospital treatment from one to six weeks, in the

different cases, resulted in complete recovery, however, except in the case of one man whose face was badly scarred. Two men returned to the work; the others took up work elsewhere. The expenses involved were met by the insurance company.

Field Engineering Methods Employed. The preliminary field surveys and maps and the wash-drill borings were made by the engineering staff of the District with Harry U. Fuller, Chief Engineer, and Charles B. Mitchell, Resident Engineer. The controlling designs were prepared in the office of Metcalf & Eddy who acted as consulting engineers upon this work.

The construction work undertaken by the District in the seasons of 1922 and 1923 were also directly under the engineers of the District.

Upon the letting of the contract for the tunnel section, to The Foundation Company in the spring of 1924, the engineering party again took to the field.

Concrete monuments were placed at advantageous points along the center line of the conduit about 500 ft. apart. Across the swamp these monuments were on 50-ft. offset points. After re-checking the line the monuments were drilled and a $\frac{5}{8}$-in. copper plug inserted on which the center line was located, with a chisel point.

At the lake end of the tunnel line a 4-ft. square target was erected on the point of land across the cove from the intake shaft, 1 000 ft. distant. On the center line of the intake a target of similar size was erected, across the lake at a distance of $1\frac{1}{2}$ miles. This line was also tied by means of two concrete monuments on the hill back of the gate house, 300 ft. apart.

All measurements were made with the ordinary 100-ft. steel tape, checked at intervals with standard, having a self-contained temperature and pull correction.

The tunnel line as originally planned was 2 100 ft. long, with an angle of 12° 26′ at Sta. 14 + 00, with a shaft at either end. Subsequently, another angle of 46° 09′ was introduced and the length of tunnel increased 32 ft. As there was a high sandy plateau covered with scrub growth between the two ends of the tunnel, which were both at lower level, and as the District was in litigation over right-of-way through this land, the maintaining of the line through the tunnel proved more difficult than it might otherwise have been.

At the southerly shaft a base line 8 ft. long was dropped a distance of 35 ft. in the shaft, and at the northerly portal a base line 6 ft. long was dropped a distance of 50 ft., to the foot of the shaft. The apparatus used for determining this line, home-made, consisted of two reels each with a 6-in. drum and 4-in. pulley, having a V-shaped notch in its face, mounted upon a rigid steel frame. This frame had a lateral adjustment and the pulley a transverse one. This permitted of fine adjustment of the wire, which was run over the pulley down the shaft by means of a 28-lb. stilling weight fabricated from 3-in. x $\frac{1}{2}$-in. angles swinging in a bucket of oil. At

the bottom of the shaft these buckets rested in a wooden scale box containing two 60-watt electric lamps illuminating a scale on white paper, shellacked, directly in front of which hung the wire. The first attempt was unsatisfactory on account of the coarseness of the wire, but on substituting a fine piano wire the difficulties disappeared. A transit with adjustable head was then set up in the tunnel about 50 ft. distant from the shaft and moved into line with the two weighted wires suspended from the reels, as described, the distance to be moved being determined by the measuring scales in the boxes referred to. Simultaneously with the final setting of the transit in the tunnel, the reels were checked by another transit located on the ground above. This operation of dropping the center line of the tunnel was executed six times at the southerly shaft and four times at the northerly shaft.

As the tunnel progressed and the concrete lining was placed, brass scales 8 in. long, having a vernier runner, were installed in the roof, and readings were taken at various times. In addition to these scales, spads were driven into wooden plugs, themselves driven into the roof about every 25 ft., and these were checked every day for line and grade.

Working grade for the excavation was obtained by means of tunnel lamps suspended from these spads, the flame being on the "A" line, or a distance of 4 ft. above the invert on the center line of the tunnel.

Cross-sections were taken by means of a wooden protractor, equipped with a scale in feet and tenths, and an arc graduated to 5 degrees, sighted by eye to the "A" line by means of two or three tunnel lamps.

The instruments used were ordinary Buff & Buff engineer's transit and Keuffel & Esser Wye level.

When the tunnel headings met at Sta. 14+55 the closure was $\frac{7}{16}$ in. in line, $\frac{1}{4}$ in. in grade, and 0.43 of a ft. in distance, — a very creditable record in view of the difficulties encountered by the field party.

For the pipe-laying in the lake intake, center line and grade were given by instrument for the first 200 ft. from the gate house. Thereafter center line was obtained from two sights on shore, consisting of a 4-ft. square target and a $\frac{3}{4}$-in. pipe painted white. Like sights were also placed for neat lines of excavation.

The engineer corps varied from time to time, the force consisting of the following men when all three sections of the work were in progress, — 1 resident engineer, 1 chief of party, 1 instrument man, 1 rodman, 1 inspector, 1 draftsman; total, 6 men. This field force was under the direction of the chief engineer, whose headquarters were in Portland and who kept in close touch with the work during its progress.

The Board in charge of the affairs of the Portland Water District consists of the following men, — William L. Blake, President; Silas F. Skillin, William H. McDonald, Philip F. Chapman, Lindsay B. Griffin; James W. Graham, Treasurer and General Manager; David E. Moulton, Attorney and Clerk; Harry U. Fuller, Chief Engineer; and Milton Thorne, Superintendent.

The representatives of The Foundation Company, under whom the work was executed, were George V. Salle, District Manager; J. Nelson Hood, Assistant District Manager, with the following superintendents successively employed, — Daniel A. Hughes, James J. Renehan, H. B. Per Lee, William U. Smick.

THE COOLGARDIE PIPE LINE IN AUSTRALIA, AND MEASURES TAKEN TO CORRECT CORROSION.

BY COL. FRANCIS F. LONGLEY.*

[*Read September 10, 1925.*]

Some twenty-three years ago a pipe line, then called the Coolgardie pipe line, was built in the southwestern part of Australia, which drew a great deal of attention from the engineering world because of its unusual character, particularly its length of about 350 miles. This pipe line was described in the Proceedings of the Institution of Civil Engineers, Vol. clxii, paper No. 3516. It began to show serious corrosion on both inner and outer surfaces within a few years, and the experience of about a dozen years of operation of the line was summarized in another paper given before the Institution of Civil Engineers (Vol. ccv, paper No. 4182).

During a recent visit in Australia the writer had opportunities to see this pipe line at close range and to learn some of the conditions of maintenance and operation during the period since these papers were published.

A brief description of the outstanding features of the construction of the pipe line and the conditions of corrosion, taken mainly from the two papers mentioned above, is herewith presented, together with a recital of measures which have been taken to minimize corrosion and a record of changes which have taken place in the hydraulic quality of the pipe line.

For much information upon these points the writer is indebted to Messrs. O'Brien and Parr, authors of the second paper above cited.

Western Australia was only sparsely populated up to about 1892. In that year there were discoveries of marvelously rich gold fields some 350 miles inland from the west coast and some 250 miles inland from the south coast of western Australia. A gold boom resulted from these discoveries, which caused a large increase in the population of that corner of Australia and afforded a basis for a permanent and wholesome growth of agriculture, of commerce, and of industry, which has made western Australia a promising land at the present time.

The coastal regions in the southwest corner of the continent are fairly well watered. The rainfall in a belt of moderate width along the coast ranges from 20 to 40 inches per year. If the rich gold fields in the interior had had a reasonably generous rainfall there would never have been the occasion to build this 350-mile pipe line.

At Coolgardie and Kalgoorlie the rainfall averages only six to seven inches a year, and there are years of record with less than four inches. With so scanty a rainfall there are no flowing streams and no generous supply of

* Of Lock Joint Pipe Co., Ampere, N. J.

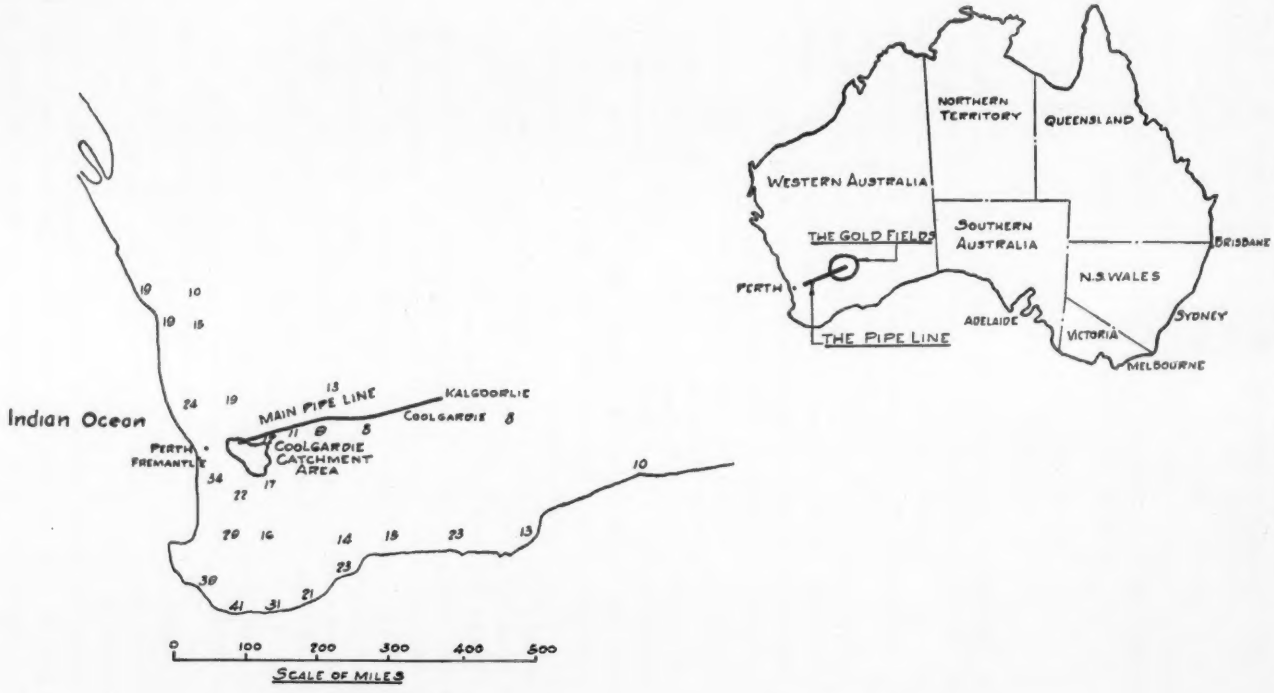


FIG. 1. — LOCATION OF COOLGARDIE PIPE LINE IN WESTERN AUSTRALIA.
(Figures show rainfall in inches per year.)

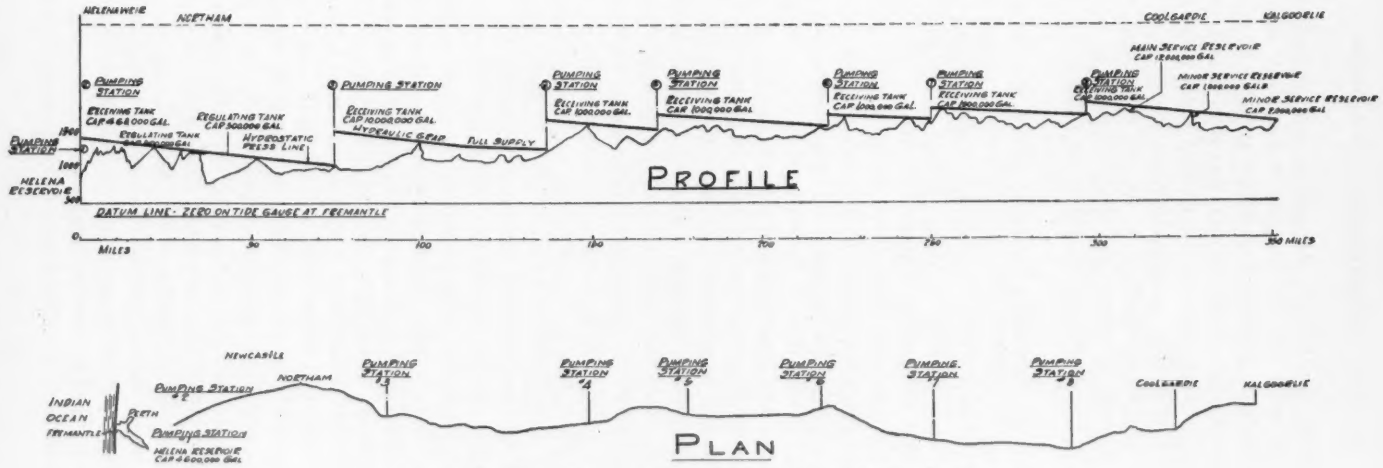


FIG. 2. — PLAN AND PROFILE OF COOLGARDIE PIPE LINE.

good ground water. In the early days on the gold fields, during a period of about 10 years, water was at a premium and at times almost impossible to get at any price. A number of expensive projects were developed for obtaining supplies locally, some depending on catching and conserving such scanty rain as fell; others drawing heavy saline water from deep wells and distilling it. The prices for water under those conditions are a good indication of the difficulties of supply. An old statement indicates that water at that time cost anywhere from 25 shillings up to four pounds per 1 000 Imp. gal. The latter price would be approximately two cents per gallon.

The government of western Australia, after a few years, became impressed with the seriousness of this situation and the economic importance of a reasonably generous and dependable supply. The result was the construction of the Coolgardie pipe line, a bold and venturesome undertaking and one that has proven of great interest.

The accompanying map (Fig. 1) shows the position of the gold field regions in western Australia, and also the location of the pipe line and the catchment area. Figures on the map show rainfall at certain points. The customary order of things had to be reversed in this pipe line. It is no uncommon thing to go a long distance into upland country and lead water down therefrom through pipe lines to the city at a lower level. Here, however, the water supply is gathered on relatively low ground within a few miles of the most densely populated part of western Australia, and is pumped up-hill and against a high friction head through a pipe line into a remote region inland with scanty population, and practically a desert if it were not for this water supply.

Description of the Pipe Line.

A profile of the line is shown in Fig. 2. The line was divided into sections, determined by the conditions of total pumping lifts. The pipe has a diameter of 30 inches. The friction in the pipe line was assumed in the design at 3.76 ft. per mile. This was the figure used in the layout of the profile and the location of pumping stations. The highest summit which had to be passed was at 307.5 miles from the origin. With a friction assumed at 3.76, the friction head to this point would have amounted to 1 156 ft. The static lift to this point was 1 290 ft. The aggregate loss at seven pumping stations, in providing for reservoirs, was 122 ft. The total of these several heads required a pumping lift of 2 568 ft. High ground between pumping stations No. 2 and No. 3 necessitated raising the water 87 ft. higher than if the slope had been a gradual one, and thus the total pumping lift to be provided for was 2 655 ft.

There were eight pumping stations in all, and the line was so divided that the first four must each be capable of lifting the water 450 ft. and the last four each 225 ft. The first four pumping stations had three pumping units each, of which any two could pump the full capacity of the line. The

last four stations had two units, either one of which was capable of pumping full capacity.

On the completion of the work, certain friction tests were run. There were two of these tests, each one extending over a period of 12 hours. One covered a length of 22 miles of pipe, and the other 12 miles. The average friction as determined in these two tests was 2.25 ft. per mile for a rate of five million Imp. gal. per day. This figure is much lower than the friction loss 3.76 ft. per mile assumed in the design. A comparison of the friction, assumed and as measured, is given herewith.

	Assumed in design.	Determined by actual measurement.
Friction, feet per mile	3.76	2.25
feet per 1 000	.712	.427
Rate of flow, millions of Imperial gal. per day	5.0	5.0
C. (Hazen & Williams)	96.	128.

From the high point of the line at 307.5 miles the water runs by gravity a distance of about 23½ miles to Coolgardie, and then another 20 miles to Kalgoorlie.

The pipe for this line was manufactured near the site of the work in a plant installed by Mephan Ferguson, the originator of the lock bar pipe. He had at that time already built other pipe lines of the same sort in Australia. The plates were purchased partly in the United States and partly in Germany. The greater part of the pipe was made of one-quarter-inch plates, and a small part of five-sixteenths-inch. The lock bar and the sleeves for the joints were obtained from Great Britain.

The greatest pains were taken when the pipe line was built, to obtain the best coating possible. Allowance had to be made for a wide range of temperature. The intense summer heat reaches 150° to 170° Fahr. in the sun, and would melt even block asphalt. Refined Trinidad bitumen was a chief component of the coating throughout. For the greater part of the line the pipes were dipped in coal tar mixed in equal parts with the bitumen. On about a quarter of the line, a California petroleum product called "Maltha," having about the consistency of coal tar, was used in its place, but in smaller proportion.

A simple sleeve joint was adopted, of the type shown in Fig. 3, the ring being eight inches wide and one-half inch larger internally than the pipe externally, to allow for the variation in the pipe and for lead space. In general, the joint was run full of lead without the use of yarn. In certain situations yarn was used, and such joints were much more troublesome than those made with lead only. For working heads of 320 ft. and less a ring having a weight of 126 lbs. was used, but for more than 320 ft. head the ring had a weight of 160 lbs. The jointing proved very effective. The leakage from the pipe line on Sections 1 to 5 was found to be 343 gal. per mile per day. From the whole length of 295 miles between the storage

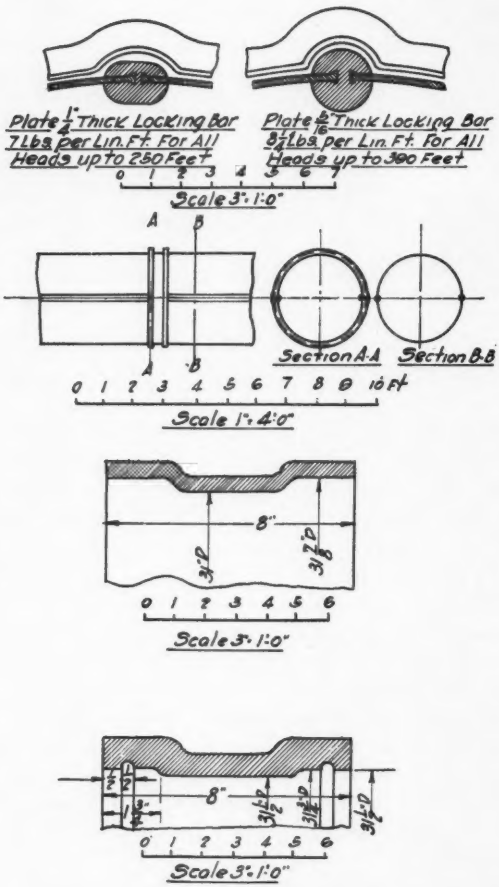


Plate 1/4" Thick Locking Bar
7 lbs. per Lin. Ft. For All
Heads up to 250 Feet
Plate 5/16" Thick Locking Bar
8 1/4 lbs. per Lin. Ft. For All
Heads up to 390 Feet
0 1 2 3 4 5 6
Scale 3": 1'-0"
A
B
Section A-A
Section B-B
0 1 2 3 4 5 6 7 8 9 10 Ft
Scale 1": 4'-0"
8"
3" D
3 7/8" D
0 1 2 3 4 5 6
Scale 3": 1'-0"
8"
3 1/2" D
3 1/2" D
3 1/2" D
0 1 2 3 4 5 6
Scale 3": 1'-0"
Sections of Sleeve Joint Rings

FIG. 3. — DETAILS OF SLEEVE JOINT.

reservoir and the last pumping station the leakage was 480 gal. per mile per day.

The cost of the Coolgardie pipe line was 5 312 pounds sterling per mile, including pipe, excavation, and backfill, and all valves and specials; but not including other structures such as the dam, the reservoirs, the pumping equipment, etc. This was equivalent to about $4.90 per linear foot.

Reduction in Carrying Capacity.

The pipe line was put into service towards the end of the year 1902. Apparently no one noticed, during the first two or three years, what changes, if any, were taking place upon the surface of the steel and in the carrying capacity of the pipe line, but between the years 1905 and 1908 a serious loss of carrying capacity was observed.

In the records and notes available to the writer, there are two different statements given of the friction in the line when new. One of these gives a value of C = 135, and the other C = 128 (Hazen-Williams formula). No reason for this discrepancy is at hand. In 1908 the carrying capacity, as measured in twelve different sections of the line, had become greatly reduced. The values of C have been computed from a large number of friction observations and the following table shows how this coefficient had fallen off in 1908 when the line had been in use about six years, and also the values at two-year intervals thereafter.

Coolgardie Pipe Line.

Values of C (Hazen and Williams formula) in twelve different sections of the pipe line, at two-year intervals from 6 to 18 years of use.

Section No.	Length in miles	1908 6 years' use.	1910 8 years' use.	1912 10 years' use.	1914 12 years' use.	1916 14 years' use.	1918 16 years' use.	1920 18 years' use.
1	1.44	111	97	87	68	69	71	71
2	41.6	109	94	74	73	71	75	75
3	46.	109	93	76	74	74	75	80
4	12.	117	104	89	88	89	88	87
5	22.2	110	101	94	90	90	91	91
6	61.9	109	97	87	84	81	79	78
7	31.6	109	98	96	95	93	89	86
8	20.2	90	82	82	83	83	80	76
9	11.9	78	69	68	71	69	69	68
10	32.6	72	68	68	69	69	68	..
11	45.1	62	57	57	56	59	59	..
12	23.5	95	88	86	87	88	87	..
	350.04							

This serious and rapid loss of carrying capacity is of course the result of tuberculation on the inner surface of the pipe. There were no deposits of silt or sand in the pipe, as the water was drawn from a high level in a large impounding reservoir. The water flowing in the pipe line must ob-

viously be classed as an "aggressive water," to produce such losses in so short a time.

Perforations of Pipe.

Perforations began to occur in the pipe early in its life. The first perforation was found in 1905, before the pipe line had been in use three years. From that time forward a great many holes were found, as shown by the following records, down to the year 1915:

Year.	Number of holes found.
1904–5	2
1905–6	27
1906–7	54
1907–8	55
1908–9	91
1909–10	177
1910–11	131
1911–12	124
1912–13	774
1913–14	966
1914–15	2 078

These perforations were of course the result of pitting, and with pits going clear through the pipe in such considerable numbers it is obvious that they must have been growing rapidly, both in number and in size. Most of the perforations were from the outer surface of the pipe. As a rule they ran from about $\frac{1}{4}$ in. to $\frac{3}{4}$ in. in diameter, but now and then reached $1\frac{1}{2}$ in.

Condition Serious.

The authorities in charge of the pipe line could not do otherwise than look upon this combination of conditions as serious, — such tuberculation within the pipe as to cause very great reduction of carrying capacity in a short time, and such corrosion from the outside as to cause extensive perforation. This was the condition within five years of the time the pipe line was put into use. A committee was appointed to investigate the causes of the corrosion and the best means of minimizing it, and they rendered a report on the subject in September, 1909.

Corrosion of the Pipe Line.

There appear to have been several factors influencing the corrosion of the pipe line; the condition of the steel plates, the presence of mill scale, the rapid deterioration of the coating, the exposure of the pipe to the hot sun for a long time before it was laid in the ground, the quality of the water flowing through the pipe line, the character of the soil, and the ground water about the pipe.

A number of samples of steel plate, from which all the mill scale had been removed, have been immersed in the impounding reservoir for a number of years. In no case has there been any isolated local pitting but a slow and slightly irregular general corrosion.

A series of corrosion tests has been carried on by the authorities in charge of the pipe line, with steel plates immersed in the impounding reservoir, and also in the main conduit. The rate of corrosion observed on the steel plates immersed in the reservoir averages about .004 in. per annum, and the rate of the corrosion of the pieces suspended in the conduit runs from two to three times as great. This difference, it would appear, must result from the fact that the strong current in the main removes products of chemical action on the surface of the steel and thus permits this action to proceed at a somewhat greater rate.

This result has been substantially checked by other observers. In the year 1906 certain tests were made by the Geological Department of Western Australia. Pieces of steel were immersed in water extracts of soils from various points along the pipe line. The maximum corrosion observed in those tests was at a rate of .004 in. per annum.

In 1908 other tests were made by the government analyst by immersing steel in the water of the impounding reservoir. These likewise indicated a rate of corrosion of about .004 in. per annum.

The corrosion of the pipe line has undoubtedly been influenced a great deal by the presence of mill scale. In rolling the plates for the pipe much of the mill scale is removed, but fragments of scale invariably stick to the steel surface, and the focus of a tubercle develops underneath one of these fragments. The attack upon the steel at a particle of mill scale is in effect an accelerated corrosion proceeding at a far greater rate than measured corrosion in the absence of mill scale. The attack appears to be most rapid close to the scale, which thus becomes undermined and ultimately separates from the steel, resulting in a reduction, if not a complete cessation, in the electrolytic action going on at that point. Observations indicated that the larger the area of unbroken scale on the steel, the longer was the time required to undermine and separate it, and the deeper were the pittings.

A plate which has been shaped by passing through rolls does not take the rolled shape along its edges for a width corresponding roughly to the distance between the rolls. This part of the plate remains practically a plain section and the rolls do not break up into minute fragments the mill scale on these plain surfaces. In the Coolgardie pipe it has been found that the pitting has been much deeper on these flat parts of the pipe than elsewhere, and such perforations as have resulted from interior corrosion are practically all on that portion of the plate.

The coating on the outside of the pipe, both the bitumen-tar and bitumen-maltha mixtures, perished early where buried in the ground, but it is said that the mixture of bitumen and maltha lasted better than the

bitumen-coal tar mixture. The deterioration of the exterior coating underground had advanced so far when the pipe line was twelve years old, that it no longer afforded any material protection against moisture reaching the steel. It was then brittle and crumbly and easily detached from the plates over large areas.

On the other hand, where the pipes were not buried in the ground, even though exposed to the weather, the coating had not deteriorated seriously at twelve years of age, and with some additional field treatment it is said to be generally in good condition at the present time.

The serious deterioration of the outer surface of the pipes underground occurred generally in loamy and clayey soils. No special studies have been made to determine just what constituents of the soil have contributed most to this corrosion and pitting of the outer surface but, broadly speaking, the worst external corrosion occurs in those parts of the line where the ground is salt. No analyses are available to show the chemical constituents of the soil at the points where serious external pitting has occurred. Some hint of the conditions may be obtained, however, from analyses of the water flowing into the impounding reservoir. These show high chlorides of sodium and magnesium, with chlorine sometimes exceeding 300 parts per million. In the alkaline marshy areas which yield water so heavily burdened with chlorides, it is not to be wondered at that steel pipe is somewhat vigorously attacked.

The coating on the interior of the pipe line has perished and become porous. Observations reported some years ago showed a rate of decay averaging about 1/100 of an inch per year. The average thickness of the tar-bitumen coating was about 1/16 of an inch and of the maltha-bitumen coating, about 1/32 of an inch. Thus within a short term of years the interior coating reached a condition where it afforded little or no further protection to the steel.

There was a long delay in putting the pipe into the trench. Some parts of this pipe, after fabrication and coating, lay out in the scorching hot sun of the arid or semi-arid parts of western Australia for months and months, and this unusual exposure appears to have been a factor in the subsequent deterioration of the coating as indicated by the corrosion of the pipe itself. The following quotation from the paper by O'Brien and Parr (Proceedings of the Institution of Civil Engineers, Vol. ccv) shows plainly the evidence tending to show the effect of this exposure.

"Nodular Incrustations. — Nodules of rust more or less numerous were found on nearly all pipes inspected. In every case the nodules were more numerous on one-half of the circumference of the pipe than on the other half. The half of the pipe that carried the more nodules had no fixed or general position relative to the crown, invert or sides of the pipes, but varied from pipe to pipe. In any particular pipe the nodules were most numerous along a narrow strip parallel to the length of the pipe, and decreased gradually in numbers round the circumference in both directions, till on the strip of pipe diametrically opposite there were generally none.

Throughout the length of each pipe the distribution of the nodules showed a remarkable uniformity on areas, or strips, parallel to the length of the pipe. A remarkable similarity was also shown in every case examined in the sizes, number, and distribution of the nodules on adjoining pipes. The distribution of the nodules on any individual pipe had no connection with the thickness of the bituminous coating, for whereas generally there was a marked difference in this on two opposite sides of the pipe, it was found that in some cases the nodules were most numerous on the side with the thick coating and in other cases where the thinner coating lay. From these observations it is apparent that the conditions which gave rise to the growth of the great bulk of the nodules arose from the exposure of the pipes to the direct heat of the sun between the time of their distribution and the construction of the main."

Certain spare pipes, made at the same time as those used in the pipe line, have been exposed to the weather and to the hot sun ever since. In every case the coating on the inside is cracked into fragments with their edges curled up along about a third of the circumference that had been exposed to the greatest heat of the sun; while the more protected part of the pipe opposite, in many cases does not show any flaws.

The water flowing through the pipe line, although a surface water, is rather heavily charged with minerals. The chlorides of sodium and magnesium are present in amounts up to four grains or more. Magnesium sulphate, magnesium carbonate, calcium chloride, calcium sulphate, and calcium carbonate are also present in quantities upwards of a grain per gallon. There is also a fair amount of organic matter. Besides this the water in the impounding reservoir, before it goes to the pumps, normally contains free oxygen well up towards the point of saturation, and one or two parts per million of carbon dioxide.

When corrosion first began to be troublesome in this line it was a commonly accepted idea that the chlorides in the water were important factors in causing this corrosion. Today, while it is recognized that these salts play a part in the character of the electrolyte, it is believed that they are not primarily the cause of corrosion, because careful observation and weighing of samples of steel submerged in the flowing stream of water in the pipe line since de-aeration has been applied, show repeatedly that where the oxygen content of the water is zero the measured corrosion of the sample is zero.

Measures for Checking Corrosion.

Whatever the cause of the corrosion it had proceeded to such a point by the year 1908, that is, after about five years of use, that the condition was looked upon as critical. The investigating committee already referred to, appointed to investigate the cause of the corrosion and the best means of minimizing it, made certain recommendations, among which the principal ones were as follows:

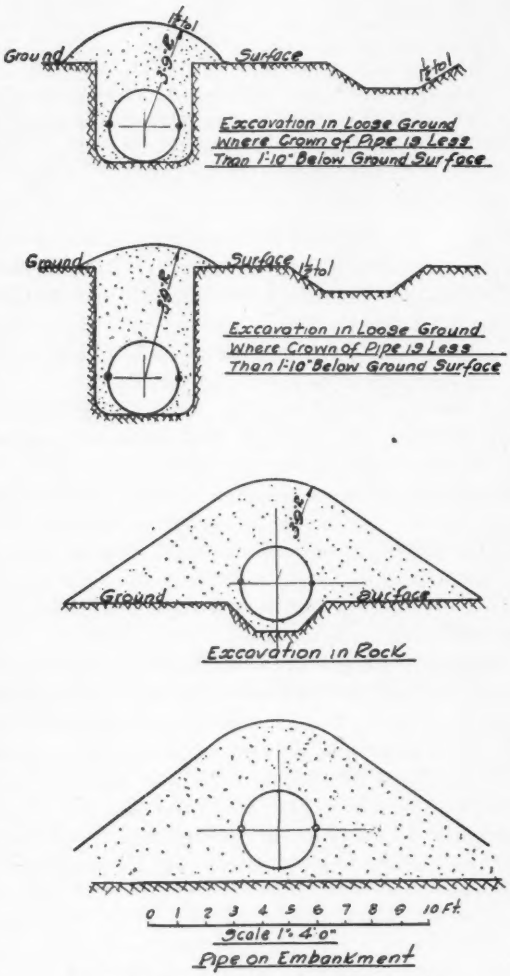


FIG. 4. — COOLGARDIE PIPE LINE — TYPICAL CROSS SECTIONS OF TRENCH.

"1. — That measures be taken to prevent air from entering the main throughout its entire length, including the construction of additional summit and receiving tanks.

"2. — That an apparatus be established as near the Helena River Reservoir as practicable to de-aerate the water entering the main and that 3 grains of lime per gallon be added to the water."

These two recommendations were shortly put into effect, but meantime another obvious remedial measure was undertaken.

When the seriousness of the condition was first known, and it was realized that corrosion in moist saline soil was mainly responsible for the increasingly serious perforations of the pipe and the destructive exterior scaling, it was decided to unearth the pipe. When the line was laid it was covered with earth in the conventional manner. Typical cross-sections of the fill are shown on Fig. 4. Now all this was to be removed. The work was pushed rather rapidly, and a statement in 1915 indicates that some 80 miles had then been uncovered, and the work was progressing at a rate of 15 miles per year. At the present time it is largely, if not entirely, uncovered, and is to be left uncovered. The ditches are all drained and all exposure of the exterior surface to corrosive soils eliminated.

The exposure of the pipe line thus to the hot sun has not resulted in any appreciable ill effects from expansion and contraction, even in places where the pipe line has been empty at times. It appears that movements must have been accommodated at the joints, and the simple sleeve joint with lead packing, already described, would no doubt act rather effectively as an expansion joint.

It was early estimated that the application of three grains of alkali would diminish the corrosive activity of the water to one-thirteenth that of the untreated water; and that the removal of all the dissolved oxygen would diminish the corrosive activity to one-sixteenth that of the untreated water. It was believed that a most effective remedy for the corrosion would result from the combined use of these methods of treatment. As the scheme practically worked out, however, they were not used in combination. The lime treatment was easy to apply without any large capital expenditure, and it was therefore started soon, while preparations were under way for the de-aeration treatment. Before the latter was ready to apply, however, the former had been given a long trial and was discarded.

The lime treatment was started in October, 1910, at pumping station No. 2, which is located only about a mile and a half from pumping station No. 1. Quicklime was slaked and diluted with water, and was fed into the suction tank at a rate of about four grains of free lime per Imp. gal. This was only a temporary arrangement, and a liming installation, supposedly intended to be permanent, was constructed at pumping station No. 1 and put into service in June, 1913, after which the lime treatment at pumping station No. 2 was discontinued. The first effect of the lime treatment was to coat the interior of the pipe and the numerous tubercles with

a heavy layer of lime. This resulted in so sharp a reduction in carrying capacity that the lime treatment was discontinued in January, 1915.

The apparatus for the de-aeration of the water was built and put into service towards the end of the year 1917.

Diagrammatic figures (Figs. 5 and 6) ate presented herewith to show the principles upon which this apparatus operates. Broadly speaking, it consists of the following parts: (1) a tank into which the water flows under control of a float valve, so that a constant level is maintained, slightly below the top of the tank, with an overflow suitably arranged; (2) an arrangement of vertical cylinders terminating at the top in a dome, from which a pipe leads away to the vacuum pump. Within these cylinders

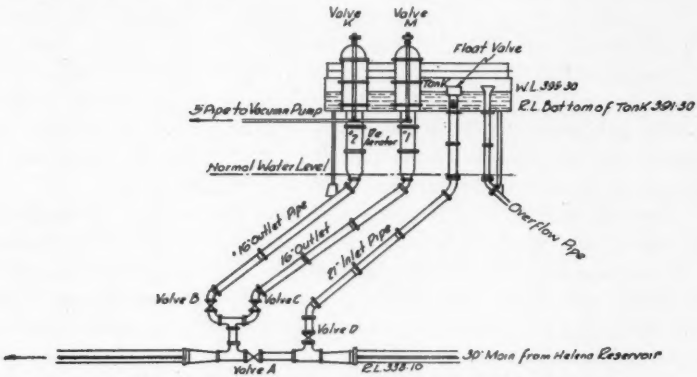


FIG. 5.—APPARATUS FOR DE-AERATION OF WATER.

the water is divided into a fine spray; first by rising vertically through a perforated annular plate as a result of the difference in pressure between the open tank and the vacuum pump; and second, by falling vertically downward through a second perforated annular plate into the cylinder and pipe running away to the reservoir. The principles involved are simple. While thus divided as a spray, the water is exposed to the reduced pressure produced by an air pump. The dissolved gases separate from the water and are removed by the air pump. The de-aerated water then flows to the pumps and is pumped into the pipe line.

The question now arises as to what have been the effects of these two treatments upon the condition of the pipe line: (1) the liming of the water, and (2) the de-aeration.

The increase in friction, or the loss of carrying capacity, is the simplest and most useful criterion of the change in condition of the interior of a pipe line. Following the early observations of diminishing carrying capacity, about the fifth or sixth year of use of the pipe line observations were started on twelve different sections of the line, for the regular and systematic determination of the friction. These have been kept up to the present time,

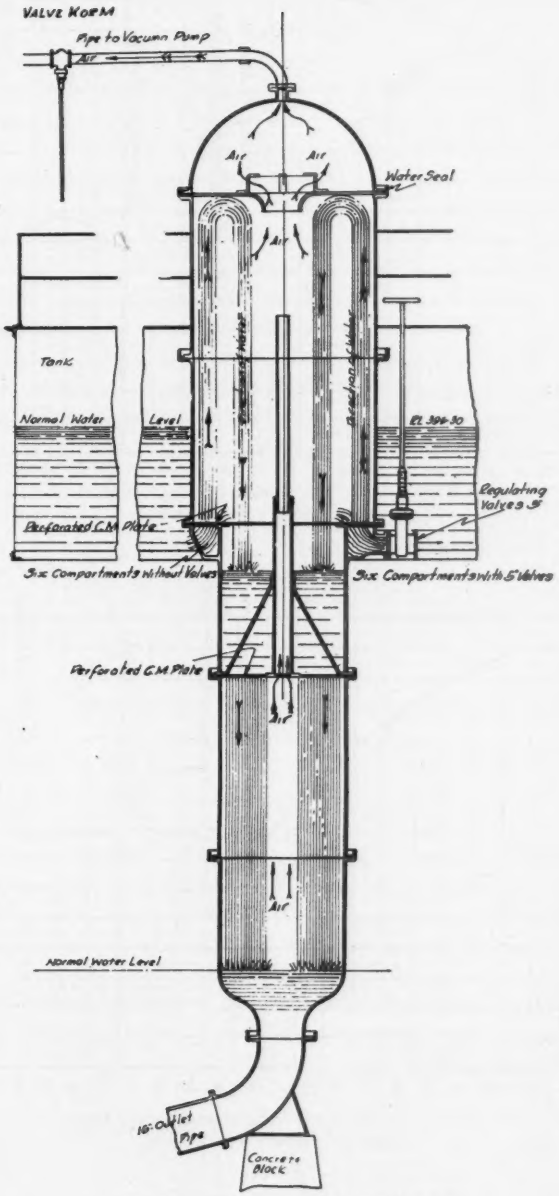
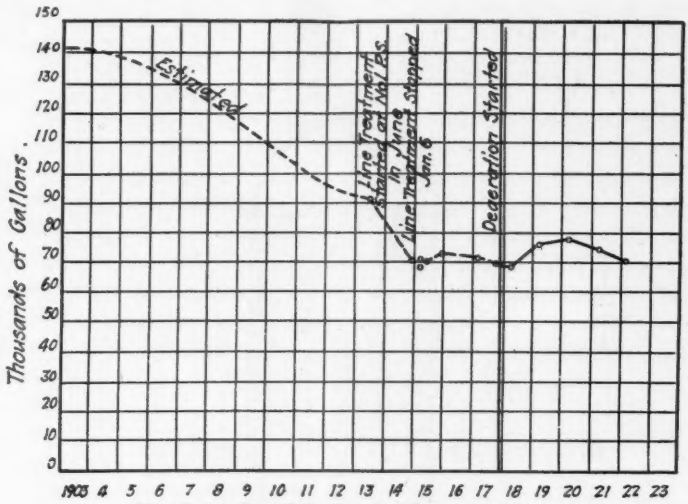
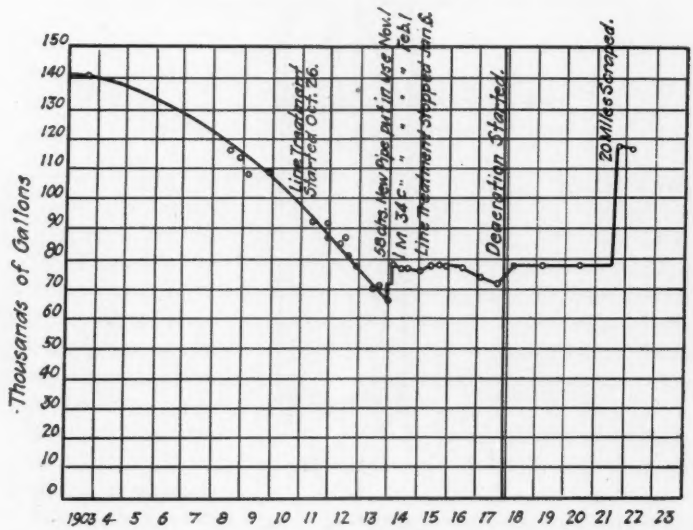


FIG. 6. — DETAILS OF DE-AERATOR.


Thousands of Gallons
Estimated
Line Treatment Started at No. 1 P.S.
Line Treatment Stopped Jan. 6
Deoeration Started
1903 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23

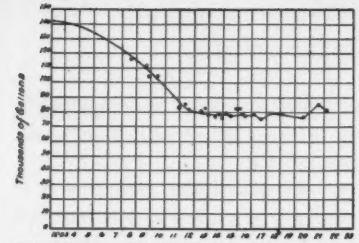
No. 1 P. S. to No. 2 P. S. Length of Section 1.44 Miles.
Maximum Available Head 85 Feet.


Thousands of Gallons
Line Treatment Started Oct. 26.
Deoeration Started.
20 Miles Scraped.
1903 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23

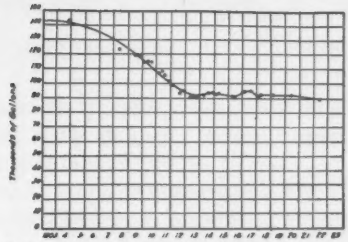
No. 2 P. S. to Bakers Hill. Length of Section 22.2 Miles.
Maximum Available Head 160 Feet.

FIG. 7.

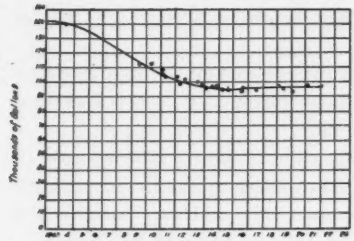
FIGS. 7 AND 8. — FRICTION TESTS ON 30-INCH LOCK BAR STEEL PIPE. (Coolgardie Pipe Line. Ordinates show rate of flow in Imperial gallons per hour for a head of one foot per mile.)



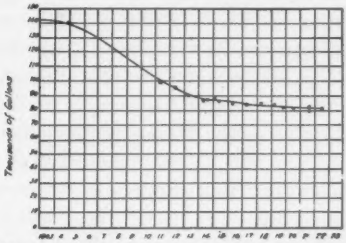
Bakers Hill to West Northam. Length of Section 11.9 Miles. Maximum Available Head 94 Feet.



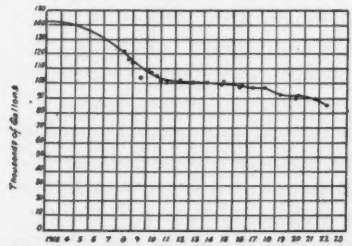
West Northam to Cunderdin. Length of Section 41.6 Miles. Maximum Available Head 194 Feet.



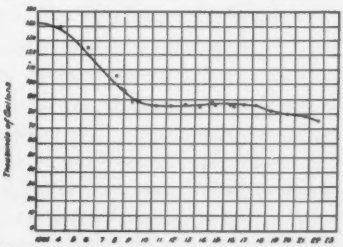
No. 3 P. S. to No. 4 P. S. Length of Section 61.9 Miles. Maximum Available Hea.. 297 Feet.



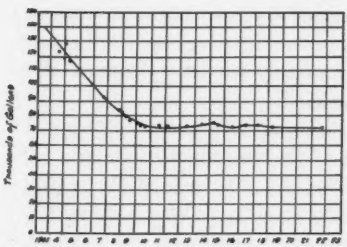
No. 4 P. S. to No. 5 P. S. Length of Section 32.6 Miles. Maximum Available Head 167 Feet.



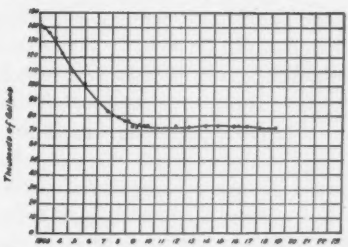
No. 5 P. S. to No. 6 P. S. Length of Section 46 Miles. Maximum Available Head 238 Feet.



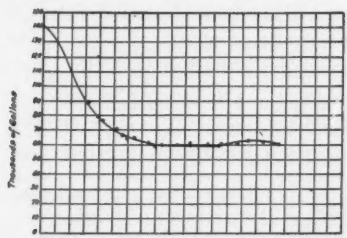
No. 6 P. S. to No. 7 P. S. Length of Section 31.6 Miles. Maximum Available Head 184 Feet.



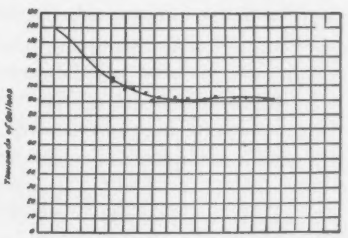
No. 7 P. S. to No. 8 P. S. Length of Section 45.1 Miles. Maximum Available Head 234 Feet.



No. 8 P. S. to Bulla Bulling. Length of Section 12 Miles. Maximum Available Head 107 Feet.



Bulla Bulling to Toorak. Length of Section 20.2 Miles. Maximum Available Head 75 Feet.



Toorak to Mt. Charlotte. Length of Section 23.5 Miles. Maximum Available Head 157 Feet.

FIG. 8. (See Fig. 7, page 436.)

and constitute a most interesting record, which is shown graphically on Figs. 7 and 8. We may study this record to see what, if any, effects can be observed of the liming and de-aeration treatment.

Each separate diagram shows, for one section of the pipe line, the diminution in the rate of flow obtainable with a friction loss of one foot per mile. All of the diagrams show a large loss in carrying capacity, dropping off sharply during the first six to ten years of service, after which they remain at a low figure without much change unless as a result of radical treatment for removal of tubercles.

The rate of flow for a slope of one foot per mile when the pipe line was new, was 14 000 Imp. gal. per hour. The coefficient "C" corresponding to this in the Hazen-Williams formula is 135*.

As has already been stated, the application of lime extended over a period of four years and three months, from 1910 to 1915. From then until the end of 1917 there was no treatment of the water. Towards the end of 1917 the de-aeration treatment was commenced and has been applied more or less continuously since that time.

The first result of the lime treatment of the water was to deposit a thick coating of lime upon the inside of the main, showing its effect markedly in a more rapid decrease in the carrying capacity of the pipe line. These deposits were naturally heaviest in those portions of the line close to the point of application. The sections of pipe between pumping stations Nos. 1, 2 and 3 are the ones which showed a marked reduction of capacity as a result of lime deposits. Beyond pumping station No. 3 no such influence of lime deposits can be detected upon the diagrams of friction tests.

This detrimental effect resulting from lime deposits might perhaps have been avoided by so arranging the lime treatment as to assure the precipitation of substantially all of the insoluble mineral before the water was put into the main. If this had been done the carrying capacity between pumping stations Nos. 1, 2, and 3 would probably not have dropped off as rapidly during the period that lime was applied.

Beyond pumping station No. 3 it is somewhat difficult to tell from the diagrams of carrying capacity whether the lime treatment made any substantial improvement in the corrosion conditions. On some of the sections this appears doubtful; on others it appears as though the lime had had some influence.

On certain sections, as, for example, between pumping stations No. 7 and No. 8, the carrying capacity had dropped at the time the lime treatment was commenced, to approximately 50% of the original capacity. The gravity section next beyond pumping station No. 8 had at that time likewise diminished to 50% of the original capacity. The gravity section still further beyond had at that date diminished to about 43% of its original capacity. This was only eight years after the line was first put into service.

* This figure is inconsistent with the value C—128, derived from the friction tests noted earlier herein. The data at hand are not sufficient to explain this inconsistency.

The curve drawn through the points representing tests, already showed a tendency to flatten out in the sections just mentioned, even before the lime treatment was applied in the eighth year of service.

In some of the other sections the carrying capacity had not fallen off quite so sharply, and it was still diminishing when the application of lime was started.

It is somewhat difficult to tell, therefore, whether the flattening out of the curves of carrying capacity, representing no further increase in friction, was the result of the lime treatment or the result of conditions which would have operated if the lime treatment had not been applied. The decrease in carrying capacity which had already occurred in October, 1910, ranging from 23 per cent. to 57 per cent. of the original capacity, was certainly a large one, and one might reasonably have expected the decrease in carrying capacity beyond that point to come to a stop soon from natural causes.

By the time the lime treatment was discontinued in January, 1915, the curves of carrying capacity in all the 12 test sections of the line had reached, or nearly reached, a fixed horizontal position. There are some variations from that statement, but they are not highly important.

During the period from January, 1915, to November, 1917, while no treatment was being applied, the curves of carrying capacity continued substantially horizontal, that is, with practically constant friction losses in the different sections of the line. If the lime treatment had been applied when the pipe line was new, and before the interior had become heavily tuberculated; and if, further, the treatment had been so arranged that practically all insoluble lime had been deposited before the water was turned into the main, then it seems clear that the lime treatment might have had an important effect in preventing tuberculation and loss of carrying capacity.

Following the application of the de-aeration treatment in November, 1917, seven out of the 12 sections of the line showed a continuance of practically constant carrying capacity. One other is practically constant except for a sharp increase in carrying capacity as a result of scraping the interior of about 20 miles of pipe. Two other sections show a slight further reduction in carrying capacity, and the other two show somewhat erratic results, with no marked tendency either to an increase or decrease in carrying capacity.

It is rather hard, therefore, to tell just what value, if any, this de-aeration treatment has had, because carrying capacity had already been seriously reduced before this supposed remedial treatment was first applied in November, 1917, and because most of the line is still in the seriously tuberculated condition which it had then reached.

Following the report of the investigating committee of 1909, it was decided to place by-passes of 3-in. uncoated steel pipe on the main conduit at suitable intervals, averaging about 20 miles apart, for the purpose of

determining the success of the treatment along the length of the main. These by-passes were used for this purpose for some time, but later devices were arranged to permit the suspension of pieces of steel directly in the stream of flow in the pipe line.

These pieces of steel have been removed and weighed and replaced from time to time in order to get a measure of the corrosive effect of the water. At the same time many examinations have been made for dissolved oxygen in the water.

Results upon these test pieces have been fairly consistent and have been found a useful guide in determining whether the de-aerating plant was running satisfactorily.

The amount of corrosion on the test pieces figures closely with the total quantity of water flowing. Cases have been noted, for example, where the total quantity dropped sharply, because of strikes at the gold fields, and the amount of measured corrosion on the test pieces also dropped sharply. It has also been observed again and again that where the oxygen content of the water is zero the measured corrosion of the sample is zero.

The de-aeration process results in a sharp reduction in the dissolved oxygen content of the water. In general the raw water runs about 9 to 10 parts per million of dissolved oxygen. In the de-aerated water the dissolved oxygen usually averages about one part per million, now and then running slightly higher and occasionally lower. In the operation of the de-aerator, for example, the perforated plates occasionally become partly clogged and until they are cleaned the spray inside the vacuum cylinder is imperfect, resulting in a lowered efficiency of de-aeration. This does not happen often. The reduction of 90 per cent., more or less, in the dissolved oxygen is said to be quite regular and dependable.

It is assumed by those in charge of the line that the carbon dioxide is removed more or less in the same proportion as the oxygen. This point has not been checked, however, with any degree of precision. There are in fact but very few tests to show the content of carbon dioxide. The few available tests indicate only one or two parts per million. The application of lime must have had for its main purpose the neutralization of the carbon dioxide. In view of that fact it is somewhat surprising that more information is not available relating to the presence of carbon dioxide in the water.

Careful tests for dissolved oxygen made on water drawn from the line show that the small residual quantity of about one part per million disappears after passing through some 20 or 30 miles of pipe. Observations have shown, further, that beyond that point the oxygen remains at zero, except in certain cases where exposure of the water in compensating tanks at the successive pumping stations permits the re-absorption of some oxygen.

A great many oxygen tests have been made along these lines. A tall, narrow bottle with a small and long neck is used for the oxygen determination, and the water is permitted to run into it through a tube running to the

bottom. A large quantity of water is run through in this way to assure through displacement of all extraneous air. The tube is then withdrawn and the reagents at once added to fix the oxygen. Numerous check results are displayed, which appear to indicate that the results obtained are reasonably precise.

Before de-aeration was commenced dissolved oxygen tests, taken at different points along the 350-mile line, showed a reduction of several parts per million of oxygen, as the water progressed along the pipe. It appears that this oxygen was used up in oxidizing the surface of the steel plate.

It is believed by those in charge of the line that corrosion in the pipe is reduced in proportion to the reduction in quantity of oxygen. In other words, if the pipe would perforate without de-aeration in five years, and if de-aeration reduced the oxygen content to 10 per cent. of the original amount, it should then resist perforation for about 50 years. Perhaps a safer basis for this argument would be to say that if the oxidation in the pipe line, prior to de-aeration, used up, say, four parts per million of oxygen, and if the de-aeration process reduced the oxygen content so that only one part per million were available for oxidation, then the length of time that the pipe would resist perforation by pitting would be four times greater than if de-aeration were not applied.

While these tests show a marked reduction in the corrosive effect of the water after de-aeration, they are not confirmed by a similar marked reduction in the corrosion of the pipe line itself; because, as already pointed out, the influence of a less aggressive condition in the water is completely obscured by the advanced stage that tuberculation and diminishing carrying capacity had reached before the de-aeration treatment was applied. Since its application, the reduced carrying capacity has remained approximately constant. It is interesting to speculate whether this would decrease still more if de-aeration were now to be discontinued, but it is not believed that further decrease would proceed at a rapid rate, if at all.

It is natural to raise the question whether the de-aeration treatment, if it had been applied when the pipe line was brand new, would have prevented, in large measure if not entirely, the tuberculation which has been the cause of the serious loss of carrying capacity.

It seems clear that such a treatment would have greatly lessened the progress of tuberculation, but it may be questioned whether it would have prevented it altogether. The treatment of de-aeration, as applied in this case, does not remove 100 per cent. of the air. Broadly speaking, it removes 90 per cent. The residual 10 per cent., more or less, is, of course, available to oxidize the surface of the steel.

The results of the weighing of some of the test pieces of steel placed in the pipe line, and the corresponding tests for dissolved oxygen, show, as already referred to, that this small residual of free oxygen is used up in passing through some miles of pipe and show, further, that beyond the point

where this oxygen is exhausted a measurable corrosion of the steel does not exist.

One might conclude, if de-aeration had been applied to the Coolgardie water supply when the pipe line was first put into service, that corrosion and tuberculation would have taken place in the part of the line nearest the de-aeration apparatus, but that beyond the point where the residual oxygen was exhausted there would have been little or no tuberculation and the loss in carrying capacity might have been very small.

The question as to the propriety and economy of applying the de-aeration method to the water to be delivered through any new pipe line would depend, naturally, upon the effectiveness of that method of protection as compared with other methods, and the cost — both capital and maintenance and operation costs — for the de-aeration treatment in comparison with the cost of assuring an absence of tuberculation and a continued high carrying capacity by other methods. Broadly speaking, it would not seem to be as good business to try to prevent tuberculation by the removal of gases for which water has so natural an avidity as to provide a surface which is not at all subject to tuberculation and which affords the most perfect possible protection to the steel lining underneath.

It is logical to note, in connection with this Coolgardie de-aeration treatment, that the quantity of water treated is very small and the selling price of the water is high. Also the total head against which the water is pumped is very great, so that the cost of operation of the de-aeration treatment is only a small percentage of the total cost of pumping.

Before the pipe line had been in use ten years the reduction in carrying capacity had become so great, especially just beyond pumping station No. 2 where conditions were aggravated by lime deposits, that it became necessary to remove some two miles or more of the pipe line and to replace it with clean pipe. That was but the beginning of a rejuvenation treatment which has been going on intermittently ever since. The extensive perforation of the pipes, combined with the serious internal tuberculation, has developed an undeniable need for extensive reconstruction work of this sort. Many miles of the line, especially those in which perforations and leakage have been the worst, have been lifted and reconstructed. This is done by removing the old pipe and at once relaying other pipe in good condition. The pipe just removed is then thoroughly cleaned and all perforations and many of the deeper pits filled up with steel welded in with an oxy-acetylene torch. The pipes are then at once recoated on the inside. This is not a dipped coating but is put on in the field where the repair work is done. The outer coating is deferred until the pipe is relaid in the trench in order to facilitate handling and to avoid damage to the coating. In general, it is expected that the repaired pipes will be relaid shortly, taking the place of other pipe removed from the line. If they are not, and if the inner coating suffers from exposure to the hot sun, it is made good before the pipes are relaid.

The repair work on the line has been done thus far with the purchase of only about three miles of new pipe. Using this, section by section, some 15 miles of pipe have been rejuvenated by cleaning out and mending perforations, and relaying. Besides this, a section, about 20 miles long, has been cleaned out with a scraper. Otherwise, out of 350 miles of 30-in. pipe, nothing had been done, up to a recent date, to make a sharp and conspicuous improvement in its carrying capacity.

DISCUSSION.

PRESIDENT TAYLOR. This is a subject, of course, which interests all particularly those who are using steel pipe.

I might say that one thing which I noticed, as Mr. Longley read the paper, is corroborated by our experience in New Bedford, where we have a 48-in. riveted steel line, and we have had occasion for various reasons to cut out two sections of it, one very near the pumping station and one perhaps two miles from it. The pieces cut out near the pumping station had a heavier growth of spongy and vegetable material than those farther up the line, and there seemed to be perhaps a little more corrosion. This, I think, bears out the testimony that the greatest corrosion, also the greatest accumulation of vegetable matters, occurs nearest the pump.

F. N. SPELLER * (*by letter*). Large-scale experience is, after all, the most satisfactory and convincing, although often very expensive.

The yacht *Sea Call*, constructed of monel metal plates held together by some steel rivets, was nearly lost at sea on her trial trip, due to the rapid corrosion of the steel in contact with this more cathodic alloy. Since then these metals have not been used together so often in contact in sea water. The lessons learned from the Coolgardie line are: (1) not to bury the pipe in corrosive soil if this can be avoided; (2) to eliminate all mill scale before coating; (3) avoid coal-tar asphalt mixtures, — either one by itself lasts longer when properly applied; (4) study both water and soil and apply preventive measures *before* the line is put into service — the proverbial "ounce of prevention" gives large returns in such cases; (5) that de-aeration is practicable on a large scale at normal temperature and may be considered together with other preventives to stop corrosion and maintain the capacity of the line.

The increased corrosion rate in the pipe line (noted by Colonel Longley) compared with the reservoir water, may be due to the influence of velocity alone and not to the abrading away of corrosion products. The velocity of flow is not given. It is not stated whether the rate of loss was measured by loss in weight or depth or pitting. It is interesting to note that, based on the greatest loss in weight found on any of the samples under test in various soils of the United States in the Bureau of Standards Tests now

* Metallurgical Engineer, Pittsburgh, Pa.

under way, the penetration is now 0.0055 in. per year, whereas the maximum rate on Coolgardie line was 0.004 in. per year.

The proper use of lime, controlled by hydrogen-ion determinations, has given very satisfactory results in some cases by the formation of a natural protective coating. The amount added at Coolgardie seems excessive (4 grains per gal.) and was apparently not under sufficient control. It would probably have been much better if this treatment had been applied before corrosion products had formed on the interior surface and if it had been applied at intervals. at least at each station.

The coating depends mainly on the equilibrium of the system $CaHCO_3 - CaCO_3 - CO_2$ and the resulting precipitation of $CaCO_3$ and other salts, so that it would not seem to be so effective (as Colonel Longley suggests) to precipitate all the insoluble salts before the water enters the line. Rather, a sufficient amount of lime should be added to carry the coating to the next treating point, and no more. With a carefully controlled system of chemical treatment, de-aeration might not be necessary.

The rate of corrosion would probably have been less except for the magnesium chloride present, although in the absence of oxygen at normal temperature these salts apparently have little effect.

In most cases the removal of oxygen from warm water results in the gradual disintegration and removal of the rust tubercles. This is one of the main advantages of oxygen removal in the intricate piping systems of large buildings. The incrustations in the Coolgardie main, however, had become thoroughly cemented as a result of the previous lime treatment, which may explain why there was no decided improvement in capacity. Probably if de-aeration had been applied without the previous application of lime, the rust tubercles would have been much reduced.

In the present condition of the line, the addition of a considerable amount of free carbon dioxide to the water (after removing most of the free oxygen) would tend to put this material back into solution and thus clean up the surface without materially affecting the rate of corrosion. Carbonic acid by itself in water has very little effect on iron.

The Coolgardie engineers were the pioneers in de-aeration of cold water on a large scale, which has never since been exceeded, although many types of smaller plants have been designed mainly for hot-water service, as described in the paper by the writer in the JOURNAL OF THE NEW ENGLAND WATER WORKS ASSOCIATION, Vol. xxxix, No. 1 (1925).

SUBSTITUTION OF MACHINERY FOR HAND LABOR IN PIPE-LAYING.

BY STEPHEN H. TAYLOR.*

[*Read December 8, 1925.*]

The replacing of hand labor by machinery on the larger jobs is interesting as showing how much can be done by that method with a few men.

In 1920 the New Bedford Water Works contemplated laying 6 600 ft. of 36-in. cast-iron pipe, in addition to the ordinary annual extensions which are necessary to keep pace with new building operations constantly creeping out beyond the limits of existing mains.

Labor at that time was very scarce; to say nothing of the excessively high wages demanded.

It was decided to purchase a 14B Bucyrus steam shovel with an extended dipper arm and a special trenching dipper of half-yard capacity, which permits the digging of a trench with perpendicular sides and sufficient depth. We afterward used a $\frac{5}{8}$-yd. dipper on the same machine with good results for the wider trenches.

The shovel travels over the trench on platforms made of 10-in. x 10-in. or 12-in. x 12-in. green oak timbers made up in sections. These sections are long enough to give a good bearing on the sides of the trench, about 6 or 7 ft. wide. Three or four sections are used and the shovel quickly picks up the section behind and places it ahead as the work progresses.

In 1921 work was started on a line of 48-in. cast-iron pipe about 19 000 ft. long. This work was located eight to eleven miles from the center of the city and the laborers had to be either boarded near the job or transported to and from the city each day.

In order to facilitate handling the pipe, which weighed four to four and one-half tons each, a 14B Bucyrus "Clamshell" and derrick, mounted on caterpillar traction, was purchased. With this outfit and gasoline-driven air compressors for handling ledge and large boulders, and gasoline-driven pumps for handling water in wet trenches, the work was accomplished by a crew of from fifteen to twenty men and two or three trucks with dump bodies.

The shovel travelled over the trench on platforms, as previously described, depositing the excavated material into trucks which dumped it into the backfill close by. The derrick closely followed the shovel, thus keeping the haul by the truck to a minimum.

With the outfit described above and reasonably good earth conditions (Figs. 1 and 2) from 120 to 180 ft. of trenching, pipe-laying, and backfilling

* Superintendent of Water Works, New Bedford, Mass.

FIG. 1. — STEAM SHOVEL AND DERRICK.

FIG. 2. — LIFTING THE PIPE INTO POSITION.

per day were accomplished. The crew was so small that transportation to and from the job daily was an easy matter.

Some sections of the work were in sand, too soft to carry the steam shovel over the trench. Under that condition the excavating was done by a clamshell bucket on the derrick, laying alongside the trench. The banks were so slippery that it sometimes required quick work to get a pipe in the trench before the bank slid in.

The work, with the exception of a little filling-in of a low section, which was completed early in the third season, was completed in two seasons; laying off during the winter months.

All sorts of earth conditions were encountered: hard pan, with large boulders, quicksand, dry, sliding sand, and even swamp where pile-driving was necessary. The same derrick with the 30-ft. boom made an excellent pile-driver.

I can heartily recommend the above-described outfit to anyone having a big job of pipe-laying to do.

The cost of the two jobs described was as follows:

COST OF 48-INCH MAIN LAID IN 1921–1922–1923.

Class "B," "C," "D," N.E.W.W.A.

Pipe $46.50 per ton, 18 813 ft.
Specials $130 per ton.

	Total.	Per ft.
Pipe and specials	$326 096.04	$17.33
Gates, hydrants, and checks	13 055.06	.69
Leadite and gaskets	6 364.32	.34
*Tools	*29 173.31	*1.56
Labor (see subdivision)	93 705.33	4.98
Lumber	4 331.11	.24
Fuel, oil, grease, etc.	7 205.01	.38
Consulting engineering	1 179.76	.06
Replacing road surface	8 929.56	.47
Miscellaneous expense:		
Travelling, telephone, telegraph, printing, accident, etc.	5 535.30	.29
	$495 574.80	$26.34

Labor may be divided as follows:

	Total.	Per ft.
Excavating, laying, backfilling, grading, and watchman	$84 598.48	$4.50
Unloading and distributing pipe	6 906.52	.37
Tools	1 574.48	.08
Preliminary work	625.85	.03
	$93 705.33	$4.98

*Includes new tools purchased which are still in good condition, to the value of $18 940.05, or about $1 00 per foot.

FIG. 3.—48-INCH CAST-IRON PIPE. CURVE WITH RADIUS OF 1 740 FEET LAID WITH STRAIGHT PIPE. LEADITE JOINTS.

COST OF 36-INCH MAIN.

6 846 ft., Class "D," N.E.W.W.A.

Laid in 1920–1921.
Pipe $64.00 per ton.
Specials $145.00 per ton.

	Total.	Per ft.
Pipe and specials	$121 191.85	$17.70
Hydrants and gates	6 052.25	.88
Leadite and gaskets	1 441.85	.21
Labor	33 139.98	4.84
Fuel, oil, grease	330.34	.05
Lumber	502.90	.07
Miscellaneous	371.59	.06
	$163 030.76	$23.81

We have used the shovel for some of the smaller jobs in the city; but for short lines scattered in various sections of the city it does not pay, as the cost of moving long distances is excessive.

Another interesting feature of the laying of the 48-in. cast-iron pipe was laying a curve of approximately 14°, or 1 740 ft. radius (see Fig. 3), with straight pipe. It was pronounced by all who saw it as a pretty piece of pipe-laying, and was perfectly tight when the water was turned on. This curve was in swampy country and mostly laid above the surface of the swamp. It was well braced to prevent the joints from blowing out.

Practically all the joints on both the 36-in. and 48-in. lines were made with leadite and braided jute packing, which resulted in a great saving of labor, especially in wet trenches where the digging and maintaining of larger bell holes would have entailed much more labor and expense.

As an illustration of the difference in cost of joints made with lead and leadite: two lead joints were made at a cost for packing, lead, and labor of $18.06 each, whereas the same items for leadite joints cost about $4.42 each. It took three men one hour and forty minutes to make a lead joint, whereas the same three men averaged from six to eight joints per hour with leadite. This does not take into account the extra cost for bell holes when lead joints are made.

AN EMERGENCY WATER SUPPLY FOR LEOMINSTER, MASS.

BY W. G. CLASSON* AND CHARLES W. SHERMAN.†

In December, 1924, the city of Leominster was threatened with a water shortage. The reservoirs from which the supply is obtained were so nearly empty that there was grave danger of their total exhaustion before the spring rains. It therefore became necessary to resort to a temporary or emergency supply to relieve the situation, at least until the reservoirs began to fill.

The only practicable source for such an emergency supply was Monoosnoc Brook. This stream flows through Leominster into Nashua River, and has a drainage area, where it enters the city, of approximately seven sq. miles. It is extensively used for power, by the Fitchburg Gas & Electric Company, just above the city limits, and by various manufacturing concerns within the city. About four sq. miles of the upper part of the drainage area are controlled by a large reservoir maintained by an association of mill owners. A very large part of the drainage area outside the city is uninhabited, but a branch brook enters near the city line which receives indirect drainage from 40 or 50 houses.

At the time under consideration, very little water was flowing in the stream, except what was drawn from the power reservoir, and this basin was so depleted that the amount available was seriously limited. The Fitchburg Gas & Electric Company has a turbine which requires 1 900 cu. ft. per min. and it was being operated for about one hour per day on five or six days of the week only; thus about 5 000 000 gal. was let down the stream from the reservoir each week. It was assumed that the run-off of branch streams would make available about 6 mil. gal. per week, or a little less than 1 mil. gal. per day. This was about half the consumption of the city, but the provision of an emergency supply to the extent of 1 mil. gal. daily would reduce the draft upon the reservoirs sufficiently to remove the danger of shortage.

Application was made to the State Department of Public Health for authority to take an emergency supply of water from Monoosnoc Brook under the provisions of Section 40, Chapter 40, of the General Laws. In granting this request, the Commissioner of Health wrote in part as follows:

December 29, 1924.

To the Board of Water Commissioners,
Leominster, Massachusetts.
Gentlemen:

The Department of Public Health has received through your engineers, Messrs. Metcalf & Eddy of Boston, an application requesting the approval of the Department

* Superintendent of Water Works, Leominster, Mass.
† Of Metcalf & Eddy, Consulting Engineers, Boston, Mass.

of the use of water from Smith Pond on Monoosnock Brook in Leominster to relieve an emergency caused by a shortage of water in the sources of water supply used by the city, and in response to this request has caused both the proposed and present sources of supply to be examined by one of its engineers.

It appears from this examination that the three chief reservoirs from which your supply is drawn, viz., Haynes Reservoir, Morse Reservoir, and Fall Brook Reservoir, have been drawn down to such levels that in case of a continuance of dry weather or of unusual cold weather there is danger that the supply will become inadequate before the reservoirs begin to fill again in the late winter and spring and, in the opinion of the Department, it is advisable to provide an auxiliary water supply before the available supply in your present reservoirs becomes wholly exhausted.

The source from which you propose to obtain an emergency supply, Smith Pond, is a small reservoir situated on Monoosnock Brook at a point where the stream has a watershed area of 7.12 square miles. Within this watershed there is considerable population and at two or three places, which have been indicated to your engineers, the brook is exposed to pollution by sewage, but it is possible to prevent the most serious of the pollutions before the water is used. It does not appear practicable to obtain water in adequate quantity to meet the present emergency from any other source and, under the circumstances, the Department approves the use of water from Smith Pond to meet the present emergency. The Department recommends, however, that before the water is turned on from this source for the supply of the city all danger of direct pollution of the brook be prevented so far as possible, that the water be treated with chlorine, and that you advise all inhabitants of the city to boil the water used for drinking.

. . . . . .

Respectfully,

EUGENE R. KELLEY,
Commissioner of Public Health.

The point at which it was proposed to take the water, Smith Pond, is a mill pond not now being used. At this point is a mill which has been out of service for a year or more, and a water wheel with an available head of 18 ft. The mill pond is of fair size and, together with the Pierce Pond, an artificial pond half a mile further upstream, serves to equalize the flow in spite of the vary abnormal draft by the Fitchburg Gas & Electric Company further upstream.

Smith Pond was an extremely favorable place at which to take the water, for several reasons. As above noted, the equalization of the flow by the ponds was an item of considerable importance. The unused mill provided a location for the pump, with the possibility of making a suction connection to the turbine case, and a discharge connection to the elevator pipe in the mill, requiring very little new pipe. Three-phase electric current was also available in the mill but a short distance from the point where the pump would be located. The amount of construction work required for the installation of the pump was, therefore, unusually small, and no interference with manufacturing operations was necessary.

Furthermore, the Viscoloid Company, which has a large mill in the southerly part of the city, had in its own plant for pumping cooling water from a brook, a pump installation in duplicate, and offered the duplicate

pump to the city for the period of emergency at a nominal rental. This was an Allis-Chalmers 6-in. centrifugal pump, designed for 1 500 g.p.m. against 250 ft. head at a speed of 1 760 r.p.m., and had a 3-phase 150 h.p. 2 200 volt motor.

The main pipe in the street in front of the mill was 10 in. in diameter, and connected directly with a 12-in. pipe from the distributing reservoir, so that all the conditions were favorable except the small size (6-in.) of the elevator pipe which was to be used as the pump discharge. In view of the excessive frictional loss which would occur in this pipe at a discharge of 1 500 g.p.m., it was thought necessary to obtain a new impeller for the pump designed for a lesser discharge, and for the head, including friction, which would actually exist at the pump. The cost of a new rotating element complete was but $230 f.o.b. Milwaukee, and this was obtained and substituted for the one belonging with the pump during the period of city operation.

To meet the requirements of the fire underwriters, a small pump room was partitioned off in the mill near the wheel house, and the pump installed in it on a heavy timber base.

Although the pollution of the stream was much less in the winter than it would have been in warm weather, the water was, nevertheless, unsafe in its raw state, and great care was therefore taken to disinfect it as thoroughly as possible by chlorination. Two Wallace & Tiernan manually controlled chlorinators were installed, with the object of having one always in reserve which could be put into service instantly in case of interruption in the operation of the other. Where dependence is placed upon a single chlorinator, any slight accident to it involves the use of untreated water until the chlorinator can be repaired. In this particular case, the duplicate installation proved absolutely essential, since the vibration due to the installation of the pump without a masonry foundation, and the nearness of the chlorinators to the pumps, would have resulted in comparatively frequent interruptions of service but for the duplicate. With it, continuous chlorination was obtained.

In accordance with the recommendation of the Commissioner of Health, water takers were advised to boil the water during the period while the emergency supply was in use. Most of them did so at first, but it is believed that after a little many discontinued this practice. The disinfection was so complete, however, that no ill effects are believed to have resulted.

In order to enable an approximate record of the quantity pumped to be obtained, pitometer measurements of the flow in the 6-in. pipe near the pump were made for various pressures, and a table prepared showing the rate of discharge corresponding to the difference in pressure on the discharge and suction of the pump. This table was used as a guide in proportioning the dose of chlorine, although, of course, the efficiency of the chlorination, as shown by the Orthotolidin test, was the governing factor.

The pump was started on January 8, 1925, and was operated in general from 12 to 15 hours per day until February 25, 1925, when its use was discontinued as the water-works reservoirs had refilled to a point to indicate that the emergency had passed. For 11 days early in February, a thaw kept the distributing reservoir full and there would have been no advantage in pumping. The emergency supply was used, therefore, for a period of 36 days. The estimated quantity pumped during this period was 31 mil. gal., equivalent to 862 000 gal. per day during the 36 days of pumping.

The approximate cost of the installation, including the removal of the pump, was as follows:

Water pipe and labor	$630.76
Moving and erecting pump, and new rotating element	460.65
Electric connections	230.43
2 Chlorinators and erection	1 335.60
Plaster board partitions, etc.	293.69
Installing heat	95.78
Cleaning cesspools and miscellaneous	172.51
Engineering	367.80
Total cost of installation	$3 587.22

The operating cost during the period of operation was as follows:

Electric current	$696.68
Labor	1 012.59
Chlorine	49.86
Rental of space in mill	600.00
Heat and lights	60.80
Miscellaneous expenses	97.21
Total operating expense	$2 517.14

Although the two chlorinators, pipe and fittings, and the extra impeller for the pump are still available, and have some value, their total cost is here included in the cost of furnishing the emergency supply which, including both installation and operation, amounted to $6 104.36. This is equivalent to $169.57 per day during which the emergency supply was provided, or $196.91 per million gal. pumped.

The cost of pumping was materially increased owing to the fact that the fire underwriters demanded that a man be kept at the plant 24 hours a day. Also rent of space in mill was for six months, as equipment, with the exception of pump, was left in place.

The total quantity of chlorine used was 190 lbs., equivalent to 6.1 lb. per million gal. of water, or 0.74 part per million. This is nearly twice as much as it was expected to use. The item of cost of chlorine includes nearly 300 lbs. still on hand, as well as the deposit on cylinders.

In accordance with the terms of the law, water could be taken for emergency supply for not over six months in any calendar year. In making its taking, the City Council awarded to the owners of the mill, for rental

of space and diversion of water, the sum of $100 per month. Although the privilege was actually exercised for but two months, including time required for installation and period when the pump was not operated, rental was paid for the entire period of six months, and the plant maintained ready for service, except for the pump, which was afterwards used to pump surplus water from the low service to the high service system.

Since the mill is still idle, and, therefore, the presence of the plant does not interfere with any operations, nothing but the pump has been removed. The city is paying a rental of $25 per month since the expiration of the period of six months covered by the taking. In the remote contingency of its being needed again next winter, a new taking could be made in 1926, and the plant put in service at very slight expense. If this were to be done, the total expense for pumping the same quantity of water as in 1925 would probably not exceed $2 600, equivalent to $84 per million gallons.

Surplus Water Pumped from Low Service to High Service System.

When the spring rains of 1925 came, all reservoirs began to fill. The reservoirs of the low-service system, which comprise Haynes, Morse, and Distributing Reservoirs, on April 5, were full and overflowing, with the exception of the Haynes Reservoir which was 1 ft. below high-water mark. Water was running to waste from the Distributing Reservoir.

Fall Brook Reservoir, which is on the high service, had not filled to within 2 ft. of the high-water mark, so the idea was conceived of pumping the surplus water from the low system into the high service system.

This was done by installing the Allis-Chalmers pump, which was used at Smith's Pond, at the junction of Pleasant and Franklin streets, where the high and low service are divided by a closed valve on a 12-in. line. Connections were made on either side of the closed valve, and by closing two other valves a direct line from the Distributing Reservoir was obtained. This proved to be an ideal location, as there were but a very few houses in the immediate vicinity of the pump that were affected by loss of pressure. Also the electric power lines ran directly over the pump.

A portable house was built over the pump and on April 26 pumping water into the high service was begun.

The pressures in the mains at this point are 74 lbs. on the low service and 100 lbs. on the high service, making a differential head of about 70 ft. This is a very low head for the pump, which was designed for 1 500 g.p.m. against 250 ft. head, and under these conditions it has been estimated by the manufacturer that the rate of pumping was between 2 200 and 2 300 g.p.m.

The pump was operated 350 hours, making a total of about 47 million gal. pumped, which was equivalent to adding over 1 ft. of water to the elevation of Fall Brook Reservoir at that time.

The approximate cost of installation, including the removal of pump and dismantling plant, was as follows:

Pipe, fittings and labor	$450.11
Moving, erecting and dismantling pump	94.99
Electric connections	85.92
Portable house	258.97
Telephone	3.50
Miscellaneous expenses	21.22
Total cost of installation	$914.71

The operating cost during period of operation was as follows:

Electric current	$779.03
Labor	199.85
Lights	3.63
Telephone	5.94
Total operating expense	$988.45

The underground valves and fittings have been left in place so that if they are needed again in the future, a pump can be installed at a very small expense. They can be reclaimed at any time at slight cost. The portable house is being used for storage, but can be used again for the pump if needed.

The total cost of installation and operation, without allowance for value of plant still in use or serviceable, was $1 903.16, equivalent to $40.49 per million gal. pumped. Comparing this figure with $196.91 per million gal. pumped at Smith's Pond, it would seem as though it was money well invested; although the two costs are not directly comparable.

Diversion of Hale Brook into Distributing Reservoir.

This stream is near the Distributing Reservoir and at such an elevation that it can be diverted into it without difficulty. It drains an uninhabited area and its taking as part of the emergency supply was approved by the State Department of Public Health.

On February 23, 1925, work was begun on the diversion of Hale Brook. A trench about 6 ft. wide and averaging 2 ft. deep was dug from the Distributing Reservoir for a distance of about 1 500 ft. to the brook.

The location for the greater part of the distance was through swamp land, and as the ground was frozen to some extent, good progress was made. The muck was cut into fair-sized chunks and readily thrown to one side, whereas if it had not been frozen, it would have been very slimy material to handle.

On March 15 the ditch was ready, but as there was enough water coming into the Reservoir to supply its needs, the brook was not diverted until April 27, when pumping at Franklin and Pleasant streets was started for the purpose of filling Fall Brook Reservoir.

There is no way of telling the quantity of water obtained from this source, but unquestionably it was helped to a large extent. About 175 acres of watershed were added to the low-service drainage area.

The cost of this work to date was $632.18, exclusive of land damages.

A FINENESS MODULUS FOR FILTER SANDS.

DISCUSSION OF PAPER PRESENTED BY RICHARD G. TYLER.

[This paper was printed in the September, 1925, JOURNAL, page 239. — EDITOR.]

PAUL HANSEN.* I think Professor Tyler is entitled to our thanks for making the investigations described in his paper. A good deal more such work is needed in connection with the examination of filter sands. The report he referred to for the American Water Works Association is one with which I had something to do as Chairman of the Committee on Filter Sands.

There is a great deal that can be determined about filter sands that might help us to analyze better the action that takes place in filters and to better select filter sands. However, I do think that the Hazen method has been extremely useful for the past thirty or thirty-five years, and thus far there has been no better method which has been adequately developed, that the Committee of the American Water Works Association feels like recommending to replace the Hazen method. Perhaps better methods may be developed, and it is through just such studies as Professor Tyler has made that they will be brought out.

There are several things that we are interested in. One is the matter of specifying filter sands for purchase. We want to use a specification that a contractor can understand, and on the basis of which he can furnish the kind of sand wanted. Another is that we would like a definition or specification that will tell us what kind of a performance the sand will give in a filter. The two do not seem to go perfectly together. So far, certainly, Hazen's method has given us the best means of specifying a sand, and it has also perhaps given us the best means of ascertaining in advance, in a general way, what a certain sand will do.

As indicated by Mr. Armstrong, for mechanical filters the Hazen terms of "effective size" and "uniformity coefficient" do not tell us all we would like to know about the sands, because in a mechanical filter the sand becomes stratified very soon as a result of the washing process, and the "uniformity coefficient" and the "effective size" mean a good deal less relative to the performance of a stratified sand in the mechanical filter than they do relative to the performance of a sand in, say, a sewage filter or slow sand water filter, which sand is not distributed or stratified after it is once placed.

In considering the condition of sand in mechanical filters, a better indication of the performance of the sand can be obtained by a diagram which shows, by sieve analysis, the stratification of sand in the filter bed. This has been done at Baltimore and at St. Louis. It is also possible after mak-

* Of Pearse, Greeley & Hansen, Consulting Engineers, Chicago, Ill.

ing an analysis of sand by the Hazen method to construct from Hazen's diagram the diagram that Mr. Armstrong has used at Baltimore, and which has been used by the engineers at St. Louis.

All things considered, the committee of the American Water Works Association feels that so far nothing better has appeared than the Hazen method. The greatest fault that we find with the Hazen method is with reference to the calibration of the sieves. I sent out a questionnaire to a large number of operators, together with identical samples of Ottawa sand which I asked them to submit to a sieve analysis. One question in the questionnaire was with reference to the calibration of the sieves. The replies showed that a surprisingly small number calibrated their sieves according to the method prescribed by Hazen; in fact, most of them did not calibrate their sieves at all, which to my mind indicated the desirability, if possible, of being able to purchase on the market standard sieves upon which one can rely as to openings and wire diameters.

There has been a good deal of work done towards obtaining such standardized screens. Quite recently there was a meeting in Philadelphia, called at the instance of the American Society for Testing Materials, at which various manufacturers and associations were represented. Also the Bureau of Standards at Washington was represented. At this meeting standard specifications for standard testing sieves were agreed upon which specifications embodied certain tolerances both with reference to the openings between the wires and with reference to diameters of the wires. If, however, these tolerances are permitted I do not think that the standard screens would be accurate enough for the examination of filter sands. There are, it is true, certain manufacturers that do make testing sieves sufficiently accurate, so that sieves of a given number, purchased from the same concern, will be quite accurately alike. It is not practicable, however, for any society to specify as standard sieves the sieves manufactured by a single manufacturer. Necessarily any standards adopted must be such that any manufacturer can reasonably meet them.

I hope that in the course of time it will be possible to reduce the tolerances so that it will not be necessary to calibrate sieves in the manner formulated by Mr. Hazen.

As for adopting terms other than "effective size" and "uniformity coefficient" — I personally am not inclined to feel that we need to be in any particular hurry about it. Those terms have become very well understood, and they have certainly stood the test of many years of use. Nevertheless, I do believe that there is room for improvement, which may be brought about by further investigation, and I trust that Professor Tyler, and other investigators, will continue their efforts and in time give us some better methods of describing and specifying sand for filtration work.

GEORGE F. CATLETT.* I have read with interest Professor Tyler's paper and am impressed with the merits of his suggestion. However, my

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Member, Committee on Filter Sand Analysis, American Water Works Association.

ideas on the subject of filter-sand specifications are somewhat along the line of the concluding paragraph of Professor Saville's discussion. None of the suggested bases, Hazen's method included, takes properly into consideration the full requirements of a filter sand. Professor Tyler, as in case of most others who have worked on the subject, assumes that water transmissibility of the sand is the controlling factor. As a matter of fact this quality does not completely represent the requirements.

If we consider the filter bed (sand and gravel) as a whole, it performs two functions. The first is a support for the real filtering medium, which in case of slow sand filters is the biological and general colloidal organic debris present in all surface waters; and in the case of rapid sand filters the colloidal inorganic matter formed with chemicals. The second function, applying only to rapid sand filters, is the uniform distribution of wash water. The second function is the one that has presented most difficulty in filter design, but the simpler as far as the beds go.

As regards the first function, the removal of bacteria and fine suspended particles is brought about in the capillary water or fluid held in the pores of the sand, the same water that differentiates between the plastic and cohesive quality of clays and coarser sand not having these qualities. The mechanism is concerned with the quantity and quality of the surface area of the sand, and the nature and amount of this surface is the controlling factor.

Perfectly clean sand, though it be very fine, is very ineffective in the removal of bacteria and fine suspended matter; as evidenced by the poor results obtained with a new bed and with a freshly washed or scraped bed, particularly if it be too thoroughly washed. The results reported by Stiles, showing abnormal travel of bacteria through clean beach sand, is, in my opinion, additional evidence of this. On the other hand, if we examine the top sand and that near the surface of a properly functioning filter bed we will find the sand particles coated with a jelly-like, colloidal film. This is mostly aluminum hydrate in case of rapid sand filters and a similar material of organic nature termed "schmutzdecke" in case of slow sand filters. Without going into the subject of the action of these films in attracting particles of solid material and designated as "absorption," we are pretty well assured that the nature of the material forming the film, and surface tension, are the large controlling factors, and if not the entire controlling factors. The finer the sand, the greater the surface area; the greater the surface tension, the thicker the film; the greater the absorption, and the more effective the filtration.

The requirement of the rapid sand filter bed for wash-water distribution is that the grading of particles shall be gradual and uniform from the larger size at bottom to finer at top; the most important factor being the provision that there shall not be an abrupt change from one size to a much smaller size. Such requirement would be similar to the provision of Fuller's specifications for concrete aggregate.

The "effective size" for filter sands, as devised by Hazen, with a size than which 90 per cent. of the sand bed is coarser, defines a condition which will exist a short distance below the sand surface, somewhat approximating the point of maximum penetration of filtering film. The conditions at the sand surface and near it are indefinitely controlled, and it is here that filtration chiefly takes place. Another objection is that unsatisfactory attempt is made to establish control factors for the entire sand bed when the requirements are different and, to a large extent, opposite in top portion and bottom portion. This same criticism would apply to most of the attempts to modify and improve the Hazen method.

The chief advantage that the Hazen method has, is that all the data that have been collected in regard to filter sands are in terms of the Hazen definition. To establish a new basis it would be necessary to collect a mass of new data in terms of the new definition, with broad observation and comparison of results. As a matter of fact, the data that are available showing comparison between the action of one size filter sand and sand slightly larger and smaller are very scant. The Ohio observations of Dittoe and Waring are perhaps the most valuable. They compared results at plants with sands varying in effective size and found that, whereas during a large part of the time the coarser sand gave as good results as the finer, over a period of time the finer sands gave fewer short periods of lessened filter efficiency coincident with peak loads of pollution. It is this necessity for considering filter efficiency from the viewpoint of maximum pollution load, which occurs infrequently, that makes it so difficult to get reliable data for comparison on this or other features of filter design. I do not think that there is really sufficient data to draw very sharp limits of sand sized requirements, even assuming the Hazen method as a satisfactory definition.

I note in Professor Saville's discussion a slight error in statement of Ohio specifications. The correct quotation of Dittoe's suggested provisional specification is, "The sand shall have an effective size between the limits 0.35 mm. and 0.42 mm. and an uniformity coefficient not greater than 1.8. Preference will be given to a sand having an effective size of 0.37 and an uniformity coefficient not exceeding 1.6, all particles of which are finer than 1 mm.

In setting our North Carolina limits we have always felt that the method of specifying filter sand was not entirely satisfactory, nor the data upon which to base limits adequate or convincing. Realizing, however, that it was highly necessary to exercise some control over what is placed in a filter bed, if we were to exclude obviously unsuitable material, and the engineer to furnish the contractor with a common basis for estimating costs, we tried to arrive at what seemed to be most suited, from limited knowledge available. We set effective size limits at 0.35 mm. to 0.45 mm., with uniformity of coefficient not exceeding 1.7. The higher limit than suggested by Dittoe was due to the fact that it seemed difficult to get commercial

sands to hold to the narrower limits except at increased cost that was hardly compensated for in the slight possible advantage. A second reason was that we have not the lime incrustation in North Carolina as in Ohio. Later the Ohio State Board of Health raised their maximum limit of effective size to 0.45 mm.

My idea of the logical method for rating filter sand is to consider the sand within a few inches of the top as one item to be covered by a specification, and cover the lower part of the sand bed under the specifications now utilized for gravel portion.

The upper portion, which might be termed the "filter bed," would include a depth representing maximum penetration of coating on sand. A specification should cover this, defining a degree of fineness or surface area. This size could only be determined by experiment, and it would seem logical to expect best results if all particles were as near the same size as possible, *i.e.*, complete uniformity as an ideal. The depth of sand that would be included in this specification would have to be determined by extensive observation in actual practice. We have enough information, however, to know that the penetration is only a short distance. This would mean that only a small amount of the sand would have to have careful grading and close definition of limits of size, with consequent decrease in cost of this sand, and saving of freight to point of use.

The remainder of the sand could be considered from the same viewpoint as the present gravel bed, the demarcation being now rather indefinite and only a question of difference in size. No very rigid limits would be required. The most important point would be the limiting of the finest size allowed, with complete exclusion of any particles that are not coarser than top filter sand, but not allowing the top of the supporting sand to be so coarse as to permit filtering sand to work down into it. A high uniformity coefficient would be desirable, with no strata considerably coarser than overlying stratum. As a matter of fact, it would not be improbable that such sand would be available in most sections from well-selected "run of bank" sources.

I have discussed this idea with several filtration engineers, and, to my surprise, have had some of them ask approval of a filter bed where they had simply placed some sand on top that they felt would meet the engineer's specification. It seems hard to get them to understand that the engineer's specification covered the whole sand bed and that if they applied it only to the top portion they would not get at all what was called for.

PROCEEDINGS.

November Meeting.

Boston Chamber of Commerce Building,
Tuesday, November 10, 1925.

The President, Theodore L. Bristol, in the chair.

The Secretary announced that the December meeting would be held at the rooms of the Twentieth Century Club on Joy Street, at which time it would be decided whether the balance of the winter meetings would be held at the rooms of the Twentieth Century Club, or the Boston Chamber of Commerce.

The election of the following members was announced:

Willard Simpson MacFadyen, Wellesley, Mass.;
Professor Charles Edward Fuller, Wellesley, Mass.;
Harry U. Fuller, Portland, Maine;
Abel Wolman, Baltimore, Maryland.

Election of Leonard Metcalf to Honorary Membership.

Secretary Gifford. On petition of ten members of the Association the Executive Committee unanimously elected to honorary membership today Mr. Leonard Metcalf, and I am going to ask Mr. Robert Spurr Weston to say a word on behalf of the Executive Committee.

Robert Spurr Weston. Mr. President and gentlemen of the Association. Possibly because of my acquaintance of over thirty years with Mr. Metcalf, I have been asked to speak for the Committee.

It is unnecessary to recite to the members of this Association, even if there were the time, the details of the professional career of its Past President, whom it has justly honored. It is enough to say that, born in Galveston on August 26, 1870, and for many years a resident of Concord, Mass., he graduated from the Massachusetts Institute of Technology in 1892. He had already had some engineering experience on the staff of Wheeler and Parks, and after graduation continued with this firm until the period 1895–97, when he taught engineering and mathematics at the Massachusetts Agricultural College. In 1897 he entered private practice, and since 1907 has been a member of the well-known firm of Metcalf and Eddy, Consulting Engineers.

Mr. Metcalf's work has been chiefly in the water-works field, and he has been concerned with the design, supervision, construction, management and valuation of works in many states and in foreign countries. His publications and his extended professional connections both evidence the

authoritative position he now holds among his colleagues and clients, while his services during the Great War in connection with the emergency construction of army buildings and other engineering structures were vital and valuable.

But we delight to honor him not only for his attainments as an engineer, a hydraulic technician and an expert on valuation, but also for his services to this Association, and his ever-helpful attitude toward his fellow members.

This honor is conferred upon our friend at a time when he is suffering from a grievous and fateful illness, the pain of which he is bearing with a fortitude as remarkable as that displayed by Socrates. I cannot trust myself to speak more along this line, and all of you appreciate my feelings. I therefore conclude by moving, Mr. President, that the friendly greetings of the members of this Association be sent to Mr. Metcalf with the communication which confers upon him this honor.

(The motion was seconded by Frank A. Barbour and carried unanimously by a rising vote.)

A paper on "The New Sebago Lake Intake of the Portland Water District," prepared by Leonard Metcalf, Consulting Engineer, Boston, Harry U. Fuller, Chief Engineer, and Charles B. Mitchell, Resident Engineer, Portland Water District, was given by Mr. Fuller.

Frank A. Barbour, Consulting Engineer, Boston, read a paper on "The New Little Quittacas Intake at New Bedford, Mass."

PRESIDENT BRISTOL. We discussed at the Executive Committee meeting this morning the matter of membership. Last year we had a membership committee which functioned well. But it seemed wise today to ask each member to act as a membership committee himself and to take a blank with him, which the Secretary can furnish, and try to secure some new member for the Association.

Adjourned.

BOOK REVIEW.

WATERWORKS PRACTICE: A MANUAL.

Issued by the American Water Works Association. Baltimore, Md.: The Williams & Wilkins Co. Cloth; 6 x 9 in.; pp. 790; line drawings, graphs and tables. $5.00.

(Reviewed by RICHARD G. TYLER.*)

The Manual of Water Works Practice was written to meet the demands of "(1) The members of water boards and commissions who shape the general policies of the works under their control; (2) the salaried officials who manage and superintend the works, and (3) the specialists who design, manage, and supervise those parts of the works of a highly technical character." This requires the treatment of an extremely wide field and results in a treatment that is brief and condensed in the extreme. In some cases briefness has been secured at the cost of clarity and the authors have, in several instances, assumed that the reader has considerable previous knowledge of the subject treated. But the outstanding reaction from an examination of the Manual is that the Council on Standardization, with its co-workers, has rendered a distinct service to the water-works profession in presenting a very large amount of most valuable material while keeping the volume of practical size.

Following the introduction there are seven sections to the Manual. The first, on the Collection of Water, discusses the problems of allocation of streams, watershed yields and storage, ground water, the protection of watersheds and the effect of industrial wastes. The average reader will have some difficulty in applying the methods outlined in that part dealing with watershed yields, due to the brevity and condensed treatment. The section on Quality of Water Supply deals with the limits of the various types of foreign matter found in water, and gives standards of quality based both on Treasury Department standards (1914) and the report of the Advisory Committee on Official Water Standards (1925). The chapters on Treatment of Water give a concise description of methods used, giving the most recent advances and practice, especially as to chlorination, aeration, softening, and application of iodine. The progress made in the application of colloidal chemistry to water purification, with the light it throws on the theory of sedimentation and coagulation, is only briefly indicated. The section dealing with the Distribution of Water contains a considerable amount of statistical data of value, and while treating the subjects usually considered under this heading, goes more into detail in regard to services, corrosion of pipes, electrolysis, and the relation between filtered water storage and filter capacity than in the average textbook on the subject. The characteristics and efficiencies of different types of installations are given under pumping station practice.

An aspect of the water-works field not usually given much space in textbooks and manuals is taken up in the section on Financing and Management, over one hundred pages being devoted to a study of water rates, assessments, taxation, price trends, valuation, and depreciation. The legal limitations on bonded indebtedness for different States are also given. In the section on Fire Protection and in the Appendix, those matters affecting the grading of cities and towns by the National Board of Fire Underwriters are enumerated in order that their influence on the general problems of municipal water supplies may be understood. In the Appendix also are given numerous standard forms, specifications, etc., which will be useful to a large number of readers.

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* Professor of Sanitary Engineering, Massachusetts Institute of Technology.

JOURNAL

OF THE

New England Water Works Association

VOLUME XXXIX

1925

PUBLISHED BY

THE NEW ENGLAND WATER WORKS ASSOCIATION

715 TREMONT TEMPLE, BOSTON, MASS.

The four numbers composing this volume have been separately copyrighted in 1925 by the New England Water Works Association.

The Fort Hill Press
SAMUEL USHER
BOSTON, MASSACHUSETTS

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FRANK J. GIFFORD, *Sec'y*,
715 Tremont Temple, Boston, Mass.

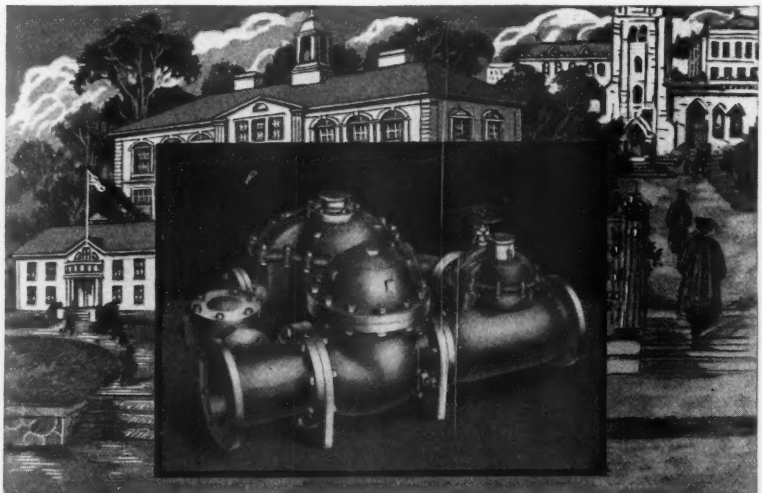
Dear Sir: Enclosed please find $\frac{\$.75}{1.50}$ in payment of charge for Certificate $\frac{}{2.25}$ of Membership in the N. E. W. W. Association ($1.50), and Membership Button ($1.00), which please mail me and oblige

Yours truly,

_____

CONTRACTORS

G. FERULLO COMPANY
General Contractors
Specializing in Water Works
31 NORTH SQUARE
BOSTON, MASS.
Telephone, Richmond 1200



287,804 SCHOOL BUILDINGS

are worth less than half the value of the property this Meter protects

THE HERSEY DETECTOR METER is installed on fire services protecting nearly $5,000,000,000 worth of property, or a sum over 50% in excess of the value of the 287,804 school buildings in the United States.

Not theory but the practical experience of 20 years has gained the unrestricted acceptance of the Hersey Detector Meter for every kind of fire service by every insurance company, stock and mutual, in the country and more than 800 water departments and water companies.

This record has no equal.

HERSEY WATER METERS

HERSEY
Manufacturing Company

Main Office & Works: Corner E and 2nd Sts., South Boston, Mass.

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FROZEN!—but not damaged

Here is an actual photograph of a LAMBERT Frost-proof Meter which has been frozen to an extent that would put the ordinary meter completely out of commission.

This is made possible by a patented, non-corrosive yielding bolt device which allows the upper and lower casing, disc chamber and gear train to part without damaging the meter in any way. Five minutes' labor the only repair cost.

The expense and annoyance from frozen water meters can be eliminated for all time through the installation of the LAMBERT Frost-proof.

It has been proved that the LAMBERT is the easiest water meter to take apart and put together again as well as the simplest, most reliable and accurate.

If you are interested in other types of meters, we make one for every requirement.

THOMSON METER COMPANY

100-110 BRIDGE STREET BROOKLYN, N. Y.

LAMBERT FROST-PROOF METERS

There is a Trident Meter for Every Clime and Every Service

THE MAINTENANCE ECONOMY OF NEPTUNE TRIDENT METERS

AQUAFAX is a 56-page, monthly magazine giving current news and accurate information regarding the conservation of water. The regular subscription price is $3.00 per year, but it will be sent free upon request to engineers, municipal heads and civic organizations.

SINCE 1892 the reputation of Neptune Trident Meters for durability in service and accuracy in measurement—without frequent repairs or replacement of parts—has grown until there are now more than 3,000,000 Tridents in use. Tridents are the attainment of an ideal to produce perfection in an entirely automatic mechanism. Proof that Trident Meters are the most dependable instruments in their field of service is evidenced in the fact that many have been in constant use for thirty-three years, and still continue to operate with dependable accuracy.

No Trident Meter ever becomes obsolete because every improvement can be adapted to existing meters of older type—can be installed easily and quickly. The oil-enclosed gear train, which prevents corrosion; the frost bottom for cold climates, preventing damage to working parts, are just two of the chief developments in water meter construction originated by Neptune engineers in order to make possible a water measuring instrument unfailing in performance.

The engineering skill, mechanical craftsmanship, and quality of materials, necessary in the production of such a perfectly balanced mechanism as the Trident Meter necessitate a slightly higher first cost. But, the price is negligible in proportion to the service Tridents render—the economy in maintenance they assure—an economy that cannot be equaled.

Waterworks men, in cities where Tridents are in use, will testify to the supremacy of Neptune Trident Meters. When you select a meter, insure lasting accuracy and low maintenance cost, by specifying Neptune Tridents.

Send for a copy of the 86-page book illustrating and describing all types and sizes of Neptune Trident Meters.

NEPTUNE METER COMPANY

Pioneers in Meter Progress

50 EAST FORTY-SECOND STREET, NEW YORK CITY

NEPTUNE METER CO., LTD., 1197 KING ST., WEST, TORONTO, ONT.

Boston	San Francisco	Los Angeles	Portland
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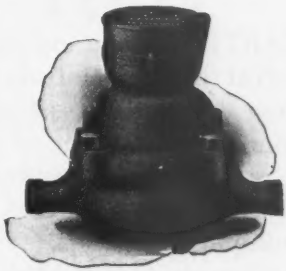
WATER METERS

The TROPIC — An all-bronze Water Meter, with connection spuds attached to the lower case. Particularly designed for warm sections of the country.



TROPIC

ARCTIC

The ARCTIC — A frost-bottom meter, especially designed for cold sections of the country.

These two meters embody exactly the same mechanical features, the only difference being the changes necessary to provide a frost breaking feature in the Arctic.

Either of these meters will be equipped with a COMPLETELY ENCLOSED intermediate train RUNNING IN OIL, if desired.

Write or wire nearest office for full information.

Please Note Change of Address

PITTSBURGH METER COMPANY

7800 Susquehanna St., Pittsburgh, Pa.

SALES OFFICES:

New York, 50 Church Street
Chicago, 5 So. Wabash Avenue
Kansas City, Mutual Building
Columbia, S. C., 1433 Main Street
Seattle, Washington
Los Angeles, Union Bank Building

WORTHINGTON SERVICE TO WATERWORKS

STARTING about eighty years ago as a builder of pumps which at that time nobody thought were wanted, this organization developed the science of pump design and grew to be the largest builder of pumps in the world. In growing the business has expanded its scope until it now includes many types of machinery all more or less closely related to pumping problems.

The products listed below are complete lines which give the freedom of choice necessary to secure the best type for each particular application.

Worthington Products for Waterworks

Horizontal Cross Compound Pumping Engines
Vertical Triple Expansion Pumping Engines
Centrifugal Waterworks Pumps
Boiler Feed Pumps—all kinds
Circulating Pumps
Vacuum Pumps
Fuel Oil Pumps
Hot Well Pumps
Deep Well Pumps
Meters—oil and water
Diesel Oil Engines
Air Compressors
Condensers—all types

Worthington service is distributed over the world. The offices in the United States are:

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BIRMINGHAM	1725-31 First Avenue	LOS ANGELES	2424-2426 Enterprise Street
BOSTON	Boston Safe Deposit & Trust Building	NEW ORLEANS	533 Baronne Street
BUFFALO	Iroquois Building	PHILADELPHIA	No. American Building
CHICAGO	Old Colony Building	PITTSBURGH	Oliver Building
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DALLAS	Magnolia Building	SALT LAKE CITY	Walker Bank Building
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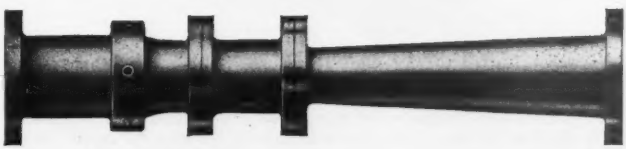
WORTHINGTON PUMP AND MACHINERY CORPORATION
115 BROADWAY, NEW YORK CITY
BRANCH OFFICES IN 24 CITIES

WORTHINGTON

5533-1C

SINCE 1891

when the first installation in the world was made by the East Jersey Water Co., the VENTURI has continued to meet the demand of American Water Works practice for an ACCURATE, PRACTICAL, and DEPENDABLE METER for main pipe lines.



BUILDERS IRON FOUNDRY

Builders of the Venturi for 34 Years

PROVIDENCE, R. I.

AMERICAN AND NIAGARA WATER METERS

American and Niagara meters are made in solid casing types and frost bottom types. The illustration above shows a $^5/_8$" x $^3/_4$" meter of the frost bottom type. Those meters having bronze outside casings are known as Americans and those having galvanized cast-iron outside casings are Niagaras. The works in all the different casings are of one best model and interchangeable. The registers may be either round reading or straight reading and may indicate cubic feet, U. S. gallons, imperial gallons or litres. All Niagara and American meters are tested and adjusted according to the requirements of the Standard Specifications for water meters adopted by the New England Water Works Association and the American Water Works Association.

Write for large catalog and prices.

BUFFALO METER CO.

ESTABLISHED 1892

2896 Main Street **BUFFALO, N. Y.**

The New Nilo

The new improved **Nilo Compound Meter** now comes equipped with a bronze body. This is a valuable addition to meter service for it eliminates the danger of corrosion and filling up due to the collecting of corrosive matter. Bronze being stronger than iron the gross weight of the meter is less, making it easier to transport, handle and install.

It also has two gate valves which allow the removal of the by-pass meter for cleaning or repairing without shutting off the line.

The controlling valve mechanism of the new **Nilo Compound Meter** is self contained and easily detached from the main body casings.

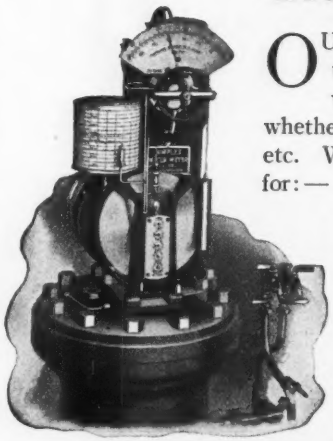
These three improvements make the **Nilo,** a long standing favorite, the unrivaled leader in its field.

UNION WATER METER CO.

Incorporated 1868

WORCESTER, MASSACHUSETTS

Is Your Pressure Low?
Are You Short on Pumping Capacity?
Do You Know Where Your Water Goes?



OUR Engineering Department will tell you how to determine your water distribution, how to find out whether or not new mains are required, etc. We can supply you with the means for: —

1. Checking up pump performance and determining slippage due to leaky plungers, defective valves, short stroking or other causes,
2. Measuring delivery of centrifugal pumps and figuring whether or not the station is up to efficiency,
3. Distributing proportionately the cost of water supplied to several districts,
4. Checking up the performance of filter beds,
5. Detecting waste or pipe leakage,
6. Recording daily amounts of sewage handled and planning future extensions, etc., etc.

THE SIMPLEX METER

VENTURI, PITOT TUBE OR ORIFICE TYPES

THE importance of exact measurements by means of a Simplex Meter cannot be over emphasized. Mr. Jeffries, Chairman of the West Chester, Pa. Water Works Committee, was able, by checking the performance of his pumping engine with a Simplex Meter, to discover that due to the imperfection and wear in the valves the slippage amounted to 300,000 gallons of water per day. This represented a daily loss of $30.00, or in other words a daily saving of $30.00, or $900.00 per month, when the valves were put in order. The Simplex Meter thus paid for itself in a month's time.

Frequent repeat orders from satisfied customers who formerly used other meters are the best evidence of merit of the Simplex Meter.

We have had many years' experience in solving water flow problems involving all sorts of conditions, and we are at all times prepared to submit general layouts involving cost and capacity, and to make explicit and complete recommendations. Write for Bulletin N26.

SIMPLEX VALVE AND METER COMPANY

Manufacturers of Meters for Water, Sewage, and Other Liquids, Rate Controllers, Automatic Air Valves, Regulating Valves, and Hydraulic Apparatus of Special Design.

6757 UPLAND STREET PHILADELPHIA, PA.

"WATCH DOG" WATER METERS

ACCURATE *DURABLE*

DISC, CURRENT AND COMPOUND TYPES

Inquiries Solicited

GAMON METER COMPANY

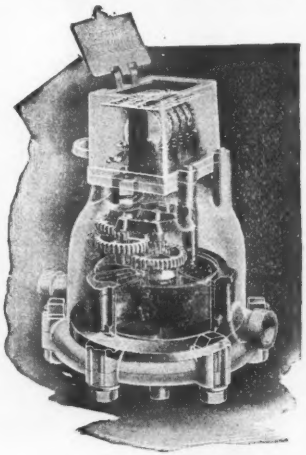
NEWARK NEW JERSEY

WATER METERS

OSCILLATING PISTON TYPE

The EMPIRE

Unrivaled for Lasting Accuracy



Made in All Sizes 5/8″ to 6″

EMPIRE METERS IN NEW ENGLAND

From the many testimonials sent us by satisfied users of this remarkable meter, we quote the following opinion of a friend in Massachusetts.

> "During the past twenty years we have had considerable experience with practically every meter on the market. After giving all a fair test and consideration we have decided on EMPIRES and for the past five years have been buying them exclusively. We find they give longer life with less repair cost and greater accuracy than any of the others."

Drop us a postal for new, fully descriptive EMPIRE circular No. 300

NATIONAL METER COMPANY

299 BROADWAY, NEW YORK

Branches in all principal cities.

There is a complete line of Badger Water Meters from the small 5/8" disc type to the large 6" Turbine Compound. You will find a type and size Badger for every service.

The Proven Water Meter

You can conscientiously specify Badger Meters and be assured that they will perform dependably and accurately day after day. They have been tried, tested and have proven themselves. That is why they are being used in ever increasing numbers, the country over.

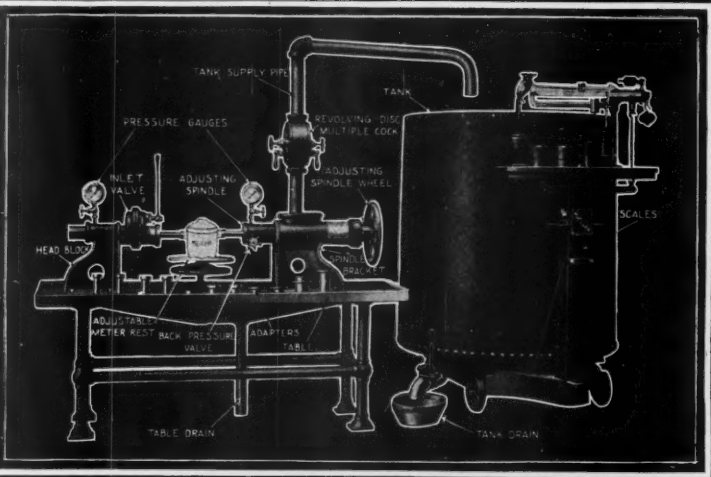
Badger Meters give satisfactory service because they are carefully constructed. They are intended to give long life, and they do.

We are always glad to render advice on meter systems and stand ever ready to demonstrate the superiority of Badger Meters — theoretically, structurally, mechanically and practically. Let us send you special circulars giving detailed information.

Badger Meter Mfg. Co., 853 30th St., Milwaukee, Wis.

111 W. Washington Street, Chicago, Ill. 367 Fulton Street, Brooklyn, N. Y.
414 Interstate Bldg., Kansas City, Mo. 1621-39 Fifteenth Street, Denver, Colo.
4038 Arcade Bldg., Seattle, Wash.

BADGER METERS



The People Demand Increased Efficiency

You can make sure your Department gets full revenue for every gallon of water used—by seeing that all meters are regularly tested for accuracy—with the

Mueller Water Meter Tester

The Mueller will prove exactly what each meter does—will enable you to adjust each meter to absolute accuracy—will save more than its cost year after year. Used and endorsed by leading municipalities. The name Mueller guarantees both Quality and Service.

Detailed description and prices on request.

MUELLER CO., Decatur, Illinois
Phone Bell 153—Auto 2131
Water, Plumbing and Gas Brass Goods
New York City, 145 W. 30th St. — Phone, Madison Square 5397
San Francisco, 589 Mission St. — Phone Sutter 3577

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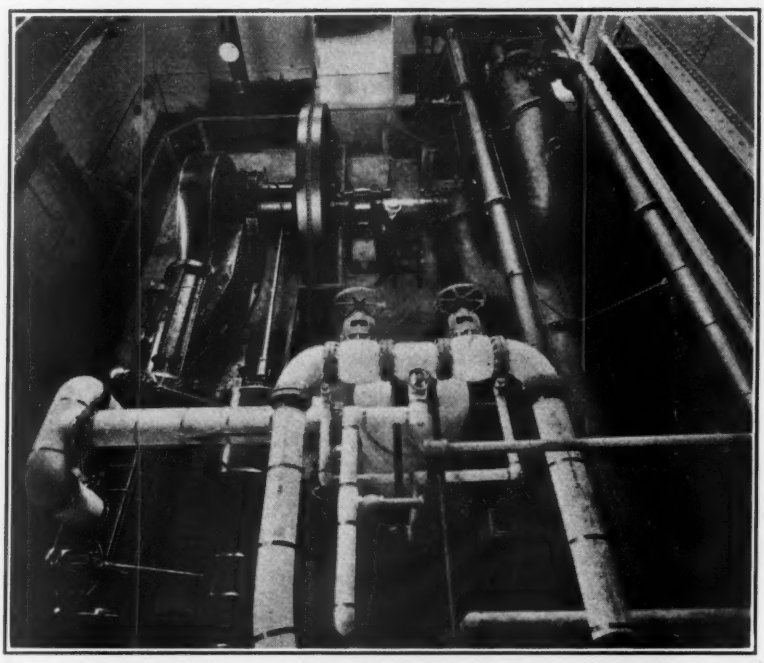
A Notable Pump Installation at Ward Street, Boston

FOR METROPOLITAN DISTRICT COMMISSION



View of 36″ Morris Machine Works Pump with direct connected 24″ x 40″ Nordberg Uniflow Engine. This unit delivers 50,000,000 gallons per 24 hours against 45 feet dynamic head at 150 rpm. Duty Guarantee 107,000,000 foot lbs. per 1000 lbs. of dry saturated steam used at 150 lbs. pressure and with 4″ absolute vacuum.

The complete equipment including condenser, primary heater, special valves and fittings furnished under one contract and responsibility and to the direction of Mr. F. D. Smith, Engineer of the Metropolitan District Commission.

Starkweather & Broadhurst, Inc.

ENGINEERS AND CONTRACTORS

79 Milk Street BOSTON, MASS. Phone Congress 1810

ATTENTION
WATER WORKS
OF NEW ENGLAND

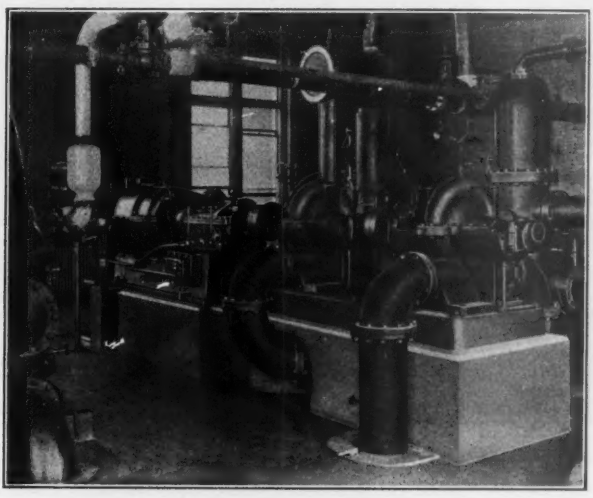
A few reasons why we solicit your inquiries on Water-Works Pumping Equipment:

First. — We make a specialty of furnishing Complete Water-Works Pumping Units of all types.

Second. — Total responsibility of installation is assumed by us.

Third. — We relieve the purchaser of every detail and turn the complete unit over to him under actual operation and with guarantee.

Fourth. — Every unit installed to date has exceeded its guarantee and has been completely accepted.



Turbine-driven Pump at the Arlington Station of the Metropolitan Water Works, Boston, Mass.

F. A. Mazzur & Co.
141 MILK STREET, BOSTON

HAYES PUMP AND MACHINERY CO.
94 PEARL ST., BOSTON, MASS.

Pumping Plant Contractors
CENTRIFUGAL, POWER, STEAM PUMPS

STEAM TURBINES
WATER WHEELS

ELECTRIC MOTORS
OIL ENGINES

RAY ENGINEERING COMPANY
136 FEDERAL STREET
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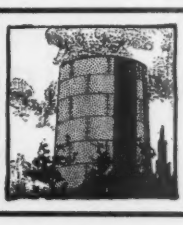
Power Plant Equipment
Steam and Heating Specialties

For new pumping equipment guaranteed by people who will make good, phone, wire or write the above.
Sales Agents for UNION STEAM PUMP CO.



Standpipes
Water Tanks
Gas Holders
and all other metal surfaces need the protection of
DIXON'S
Silica-Graphite
PAINT
BOOKLET NO. 67-B
JOSEPH DIXON CRUCIBLE CO. Jersey City, N. J.

WE announce our appointment as Sales Representatives of DAYTON-DOWD COMPANY, of Quincy, Ill., Manufacturers of Centrifugal Pumping Machinery. After exhaustive investigation, we present this line of equipment to the Trade in New England as being of the highest grade and thoroughly modern in design and manufacture.

We are prepared to furnish DAYTON-DOWD pumps in all sizes and for all classes of service, in steam, motor, gasoline and belt drive types, and solicit your inquiries, assuring you of our best efforts in your sales and service requirements, and of our appreciation of your continued confidence and patronage.

POWER EQUIPMENT CO.

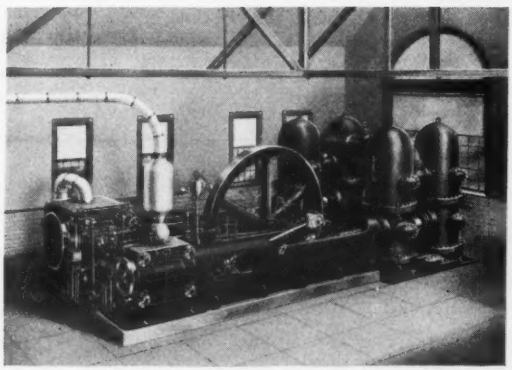
131 State Street, **Boston, Mass.**

MURRAY IRON WORKS CO.

(INCORPORATED 1870)

BURLINGTON, IOWA, U. S. A.

Builders of High Duty Pumping Engines



Murray High Duty Crank and Fly Wheel Pumping Engine, Opposed Type

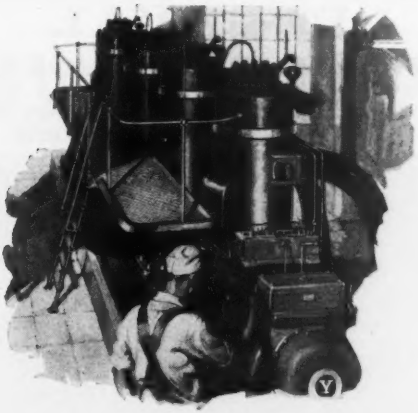
Engineers, Iron Founders, Boiler Makers

Corliss and Una-Flow Engines

Water-Tube, Fire-Tube and Internal-Furnace Boilers

Builders of Complete Power Plants

PLEASE SEND US YOUR SPECIFICATIONS AND CALLS FOR BIDS



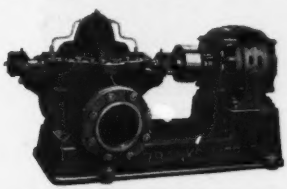
More than 90,000 h.p.
in Pumping Stations alone

Over 90,000 horsepower of Type "Y" Engines are today furnishing power for pumping stations and the number is constantly increasing.

This steady change to Type "Y" Diesel power is the natural result of operation economies that have been accomplished during the past ten years.

In waterworks service, the Type "Y" Diesel effects a saving of 50 to 75 per cent of the cost of steam or purchased power — with absolute dependability and less attention than is required in operating a steam plant.

The Type "Y" Diesel is a 2-cycle valveless airless injection cold starting engine — actually simpler than even a slide valve steam engine.



More than 800,000 horsepower of Fairbanks-Morse oil engines are in daily operation in industrial, central station, and marine service. This unequaled acceptance points not alone to the economy of Diesel power but to the proved dependability of the Fairbanks-Morse Type "Y" Engine.

And the pumps, too, should be Fairbanks-Morse.

Just as electric motor development took a great step ahead when Fairbanks-Morse originated ball bearing motor construction, so the use of ball bearings in the new "Fig. 850" and "Fig. 870" Fairbanks-Morse Pumps has paved the way to higher pumping efficiencies and new economies. This is simply representative of the advanced construction that is found in Fairbanks-Morse Pumps for practically every duty. Centrifugal or piston types; motor, steam or oil engine drive; gear driven, belt driven, or direct-connected.

One of our engineers will gladly give you facts and figures. Detailed information on Diesel Engines, Pumps, or combined units, will be mailed on request.

FAIRBANKS, MORSE & CO., Boston

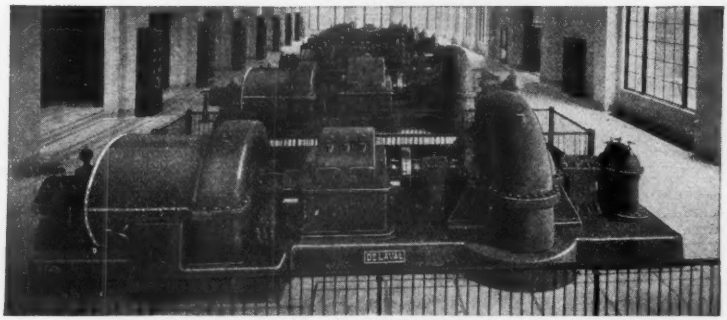
Manufacturers Oil Engines, Pumps and Electrical Machinery

Twenty-eight branches in the United States, each with a service station.

FAIRBANKS-MORSE
Diesel Engines - Pumps

DE LAVAL
CENTRIFUGAL WATER WORKS PUMPS

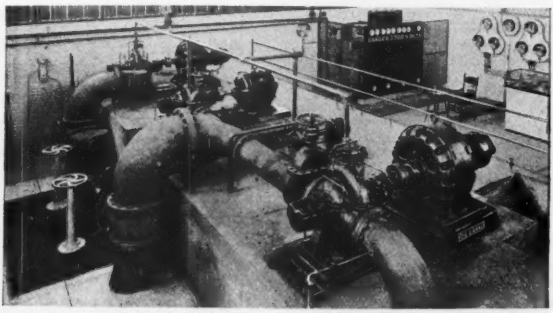
Supply 200 American Municipalities with over 5,000,000,000 gallons daily.



FAIRMOUNT PUMPING STATION, CLEVELAND, OHIO.

The largest Turbine driven pumping station in the United States. Total capacity 300 million gallons per day against heads from 85 ft. to 400 ft.

Cleveland has thirteen units installed totalling 600 million gallons per day. A fourteenth unit on order will have the unprecedented capacity of 60 million gallons against 270 ft. maximum head. Chicago has fourteen DE LAVAL units installed and on order totalling nearly 900 million gallons per day.



A TYPICAL SMALL DE LAVAL STATION, BROCKTON, MASS.

The De Laval Company announces their New England representation was transferred January 15, 1925, to

TURBINE EQUIPMENT CO. *of* NEW ENGLAND
CHAMBER OF COMMERCE BUILDING
80 Federal St., Boston

This company is under the direction of F. R. C. Boyd, President, who has been connected with De Laval representation in New England for over fifteen years.

Ask for De Laval Publication.

DE LAVAL STEAM TURBINE COMPANY
Trenton, N. J.

What We Mean By Service

EVERY DOT MEANS A W&T INSTALLATION

THIS map hangs on the wall of our General Office in Newark—a constant reminder to our staff of their responsibility for over six thousand installations of W&T equipment and processes. ¶To keep every one of these installations in constant operation, to instantly respond to calls for expert assistance and to perform with efficiency, dispatch and economy such duties as our customers require—that is the purpose of our nation wide service organization.

"The only safe Water is a Sterilized Water"

TECHNICAL PUBLICATION NUMBER 42 "CHLORINE IN SEWAGE PURIFICATION" WILL BE MAILED ON REQUEST

WALLACE & TIERNAN
COMPANY, INCORPORATED
Manufacturers of Chlorine Control Apparatus
NEWARK NEW JERSEY

Founded 1853 Incorporated 1863

MERRIMAC CHEMICAL 1863 COMPANY

FILTER ALUM

Aluminum Sulphate

A basic, uniform product which has been used successfully by the leading water filtration plants in New England for many years.

Our location and shipping facilities place us in a position to offer insurpassable service and make us the logical source of supply for all filter plants in New England.

The aid and advice of our technical staff has often proved of great value to our customers. It is always at their service.

MERRIMAC CHEMICAL CO.

148 STATE ST., BOSTON, MASS.

Works:

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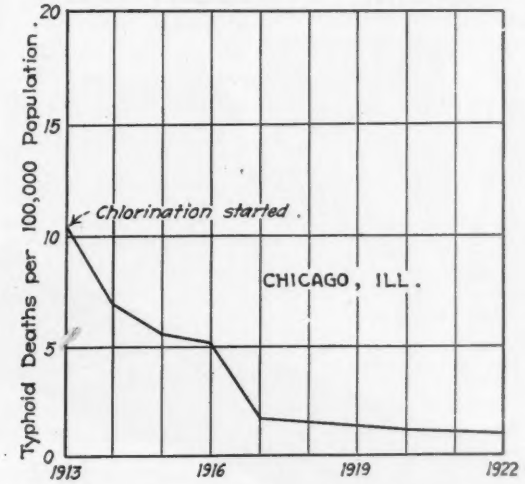

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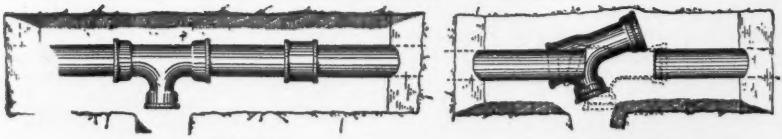

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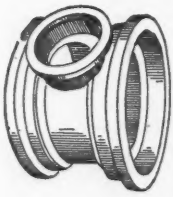

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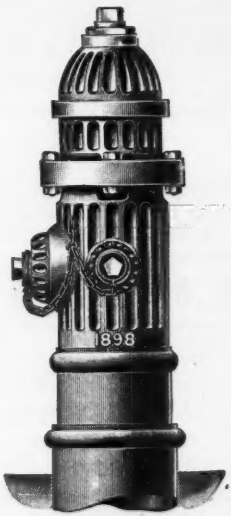

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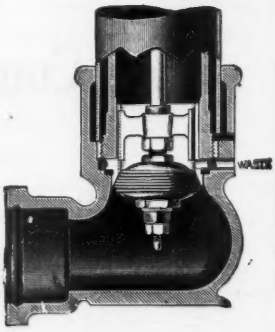

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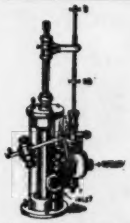

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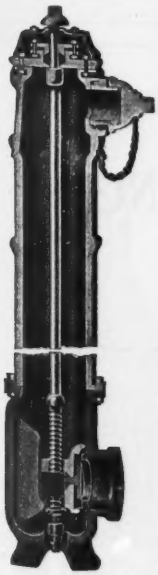

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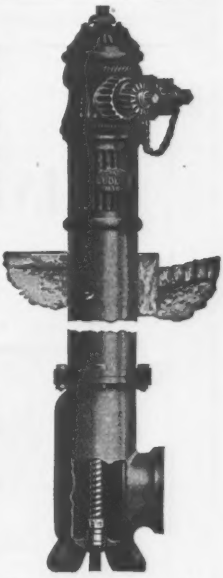

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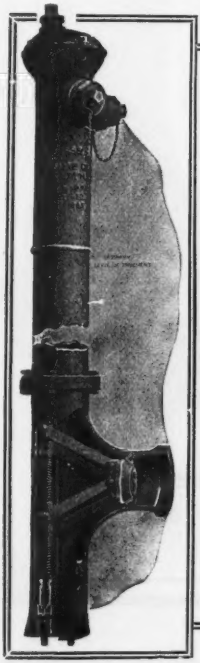

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BECAUSE this principle gives great power to open or close the gate just when it is needed, and speed in movement when power is unnecessary.

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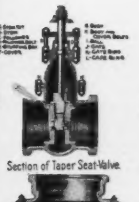
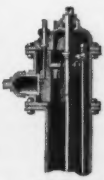
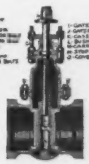


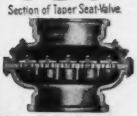
Section of Taper Seat-Valve.



Hydrant with Independent Nozzle Cut-off.



Section of Parallel Seat-Valve.



Section of Vertical Check-Valve.

Section of Vertical Foot-Valve.

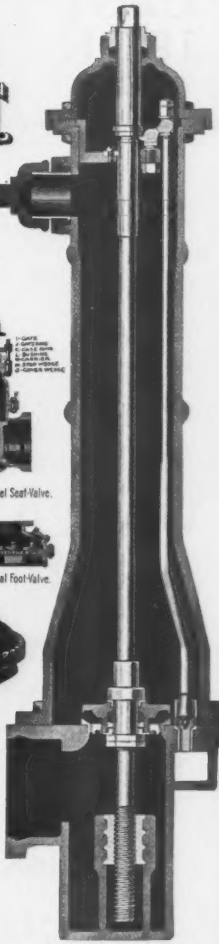
Horizontal Check-Valve.

Vertical Foot-Valve.

Hydrant with Water Crane Attachment.

Indicator Post.

Water Crane with Automatic Drip Valve.



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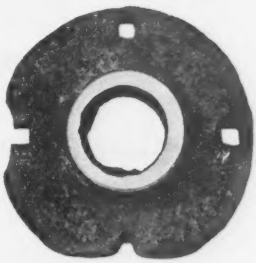

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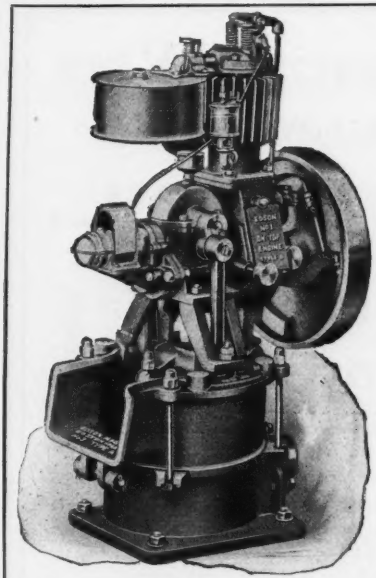

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